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A BIOLOGICAL EXAMINATION OF LAKE MICHIGAN

IN THE

TRAVERSE BAY REGION

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WITH THE FOLLOWING APPENDICES

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INTRODUCTION.

During the summer of 1893 the Michigan Fish Commission entered upon a biological study of the Great Lakes by maintaining a party on Lake St. Clair. In the report of that two months, written by the director of the laboratory, Professor J. E. Reighard, are given in full the reasons which led to the inception of the undertaking and the aims which its promoters held in view. A study of the life of the lake in all its manifold interrelations and especially of those factors which bore upon the welfare of the food fishes in general and the young whitefish in particular were the ends sought. On the attainment of these ends depends the determining of those conditions most favorable for the fry, and hence the character of the places in which they should be planted. Those who may doubt the propriety of such undertakings as this will find in the report just cited (Reighard, 95*, p. 1–5) an extended and convincing discussion of the question in its various bearings.

Ever since its establishment by legislative enactment, which named specifically "the cultivation of the whitefish" among its duties, the Michigan Fish Commission has been active in effort in behalf of this important and diminishing food supply. The work of the first year of lake investigation on Lake St. Clair had been carried on in the waters of a great spawning ground of the whitefish, and it seemed wise in the second year to transfer operations to a locality which was the home of this species throughout the entire year, and which afforded hence an opportunity of studying it continuously in its natural environment. The absence of Professor Reighard in Europe prevented his taking charge of the work, and the writer, who had been his assistant during the previous summer, was asked to assume control. The opportunity was all the more readily accepted since it was joined with the express desire on the side of the Commission that the general aims of the past be kept in view and that the whitefish be made the object of especial study for the purpose of ascertaining definitely the character of its food and the life of the young which had been hitherto an absolutely unknown quantity.

The exact location of the laboratory was a matter of great importance, and in company with the superintendent of the Commission, Mr. S. Bower, I visited the Traverse Bay region. Charlevoix seemed the most available location and was selected finally by the Board of Commissioners as a center for the summer's work. A shop on the shore of Round Lake was rented and fitted up as a laboratory. An adjacent building, in which

* References to the papers cited at the close of the report are indicated in this way.

was located a small hatchery of the Commission, furnished abundant conveniences in the way of aquaria, and running water for the permanent accommodation of fish and larger forms. In this building, which was located on a fine dock, were kept the nets, dredges, trawl and other large apparatus. The laboratory proper was well equipped with tables for microscopic work and shelves for books, glassware and other necessities. A couple of tables in the center of the room held small glass aquaria and a zinc topped table near the south side afforded an opportunity for such work as required running water. Immediately north of the laboratory was a small dock from which pure water could be dipped out of Round Lake, and where in fact on more than one occasion various young fry were landed with a simple dip net. (See Pl. IV.)

The laboratory was well equipped with glassware, reagents, etc., by the Fish Commission, and the various forms of collecting apparatus were also provided by them. Most of this was the same as that used the previous year and was sufficiently described in Professor Reighard's report. In addition there was used a small trawl of six feet beam and a new form of towing net for surface work, known as the "torpedo." The trawl was of the ordinary type and the torpedo net is described elsewhere in this report. A rake dredge of the type ordinarily employed in marine work was made for our use and proved highly satisfactory in many localities. To the University of Michigan the party was indebted for the loan of numerous microscopes and accessories, various laboratory apparatus and finally an extensive library of special literature. Especial thanks are due the University authorities for their cordial cooperation in the underaking.

Small boats served the purposes of the party for the preliminary work and for occasional short excursions. Later a sailing boat of some size was tried for work on Lake Michigan, but proved too uncertain for continued use, and for the extended trips on the lakes in connection with the plankton work of the last three weeks a small fishing tug was chartered. This was the "Minnie Warren," of 13 tons capacity. Her captain, John O'Neil, has been a successful fisherman for many years and is well acquainted with all the shoals and reefs of the region on which fishing is or has been profitably pursued. We were thus enabled to ascertain the exact location of exhausted fishing grounds and to make collections on them for comparison with material obtained from other points. In general, only single day trips were made, but on one occasion a longer trip of three days to Beaver Island was planned. The first day was spent in making collections at various points en route. It had been planned to investigate the fishing grounds near the island on the second day and return the third by a different route, but a severe storm on the second day upset our calculations and forced us to spend the larger part of the second day in harbor and on the island, and to condense the work of the second and third days into the last. The route of the party may be followed on the map by the numbers of the plankton stations; ix to xiii were made the first day; the night was spent in the harbor at the northern end of the island; xiv was made the second day before the storm broke, after which we returned to the harbor for a compulsory stay of 24 hours, and xv to xvii were stations on the return route of the third day. On the first day some of the party were landed at the lower end of the island and visited the small inland lake there, and on the morning of the third day, while it was yet too rough for work outside, a trip was made to the lake in the northern part of the island. Collections were taken from these

lakes for comparison with material obtained in the big lake and in the waters of the main land. This trip afforded much valuable evidence on the present condition of the whitefish grounds, some of the best of which in this entire region were visited and studied. On one other occasion, the day set for work in Grand Traverse Bay, we were overtaken by a storm and compelled to return without accomplishing the object of the trip. Otherwise the work suffered no interruption from bad weather.

The laboratory was opened June 28, when three only of the force were present. Two arrived but a few days later, and these five continued at work until September 1. Their names, and the special part of the work to which the attention of each was devoted, are appended:

Professor Henry B. Ward, University of Nebraska, Lincoln, director; quantitative work, and worms.

Professor C. Dwight Marsh, Ripon College, Ripon, Wis.; vertical distribution and Copepoda.

Dr. Charles A. Kofoid, instructor in zoology, University of Michigan, Ann Arbor; Protozoa.

Dr. Robert H. Wolcott, instructor in zoology, University of Nebraska, Lincoln; Hydrachnida and Insecta.

Mr. Herbert S. Jennings, assistant in zoology, Harvard University, Cambridge, Mass.; fishes and Rotifera.

The following gentlemen who were with the party about a month rendered very valuable assistance in their special line. To some extent they were enabled to examine material collected at other times by various members of the party:

Professor Edwin A. Birge, University of Wisconsin, Madison, Wis.; vertical distribution and Cladocera.

Mr. H. D. Thompson, instructor in natural science, Moline High School, Ill.; plants.

Mr. Bryant Walker, Detroit, Mich.; Mollusca.

It is scant acknowledgment of continued aid and encouragement to say that whatever results the work may have yielded are due to the efforts of these gentlemen. All of them worked under great disadvantages, but with an enthusiasm which begets success, and their best services were offered without compensation in the cause of science. More than this some of them brought to the work of the summer expensive pieces of apparatus without cost of any kind to the Commission. Thanks are especially due to Messrs. Birge, Marsh and Walker for such courtesies. It is only fair to Mr. Thompson, who had charge of the botanical part of the work, to say that he joined the party at a very late date and most unexpectedly, to fill a vacancy, so that he was handicapped by lack of knowledge of the region and of the early work of the party, and was further hindered by poor health during his stay in Charlevoix. In spite of all these disadvantages he did a large amount of work as shown by his report appended hereto.

Valuable assistance in the work of identifying the algæ was given by Mrs. Prudence W. Kofoid. Dr. R. Halsted Ward, Troy, N. Y., was with the party for the last of the season and assisted in the botanical work. After the laboratory closed he voluntarily spent an entire week making collections at various points on the system of connecting lakes in the extreme northern part of the peninsula (see map). These were sent to various members of the staff and were of great value for comparison with the data obtained at Charlevoix. The various stations at which he

made collections are indicated on the map by arabic numerals; from these the considerable extent of this assistance may easily be estimated.

The laboratory was honored by numerous visitors, including some scientific men of prominence, who made stays of varying lengths while investigating special problems. Professor W. A. Locy, of Lake Forest University, spent some time there in researches on fish embryology, and Professor C. K. Wheeler, of Michigan Agricultural College, was called to Charlevoix by the discovery of a member of our staff that the Russian Thistle was growing in the vicinity of the laboratory. This was the first reported occurrence of this pest in the lower peninsula. But a small number of plants were found, these in a limited area near the shore and not yet mature. Their timely destruction undoubtedly prevented the species from obtaining a foothold in the region and saved the State a considerable expense for its eradication. Miss Weidemann, of Michigan University, also spent some time in the laboratory, being engaged in the study of various fish fungi.

Mr. Dwight Lydell and Mr. Jesse P. Marks, old and skilled employés of the Fish Commission, devoted their time and energy to assisting the work of the party in various ways. The collections of parasites and of fish stomachs were particularly due to their efforts.

Collections were made and sent to the following persons, who have agreed to report upon the same:

Dr. G. Eisen, San Francisco; Oligochæta.

Dr. R. Blanchard, Paris, France; Leeches.

Dr. W. McM. Woodworth, Harvard University; Planarians.

Dr. C. B. Davenport, Harvard University; Bryozoa.

During the first five weeks the energies of all were devoted to qualitative work on the flora and fauna of the waters. Tows at surface and bottom were taken and examined in the morning, and the afternoon was used for collecting trips to various points. In this way there was obtained a general picture of the life, first in Round Lake on which the laboratory was located, then of Pine Lake and finally of Lake Michigan. Lists were kept of the forms identified, and for this purpose the blank reproduced by Reighard (p. 10) was employed. It should be said that this collective blank, which has been in use for years at the Agassiz Marine Laboratory in Newport, is a form compiled and introduced by Dr. W. McM. Woodworth, of Harvard University. The season at Charlevoix was the second year of its use for lake work, and it has continued to answer its purpose admirably and with very little modification. The blank for recording parasites and that for individual species, given by Reighard (p. 9), were also used at Charlevoix. During our stay it was customary to send some one of the assistants out on fishing tugs from time to time, and to secure in that way specimens of various fish for investigation; the stomach contents of a large number and the parasites of others were obtained and preserved for study.

While the party was thus engaged in recording the mutual relations of the life in the waters, information was secured at the same time as to the character of the waters, of the fishing grounds and of the fish supply. All these were made the basis of the last three weeks work, the quantitative plankton studies, which are treated in detail later.

To the United States Fish Commission, through Commissioner Marshall MacDonald, the party was greatly indebted for the loan of valuable apparatus. At the request of President Whitaker, of the Michigan Board,

Mr. MacDonald sent for use in Charlevoix a Tanner deep sea sounding machine* of improved pattern, a Sigsbee water bottle, and a set of Negretti and Zambra deep sea thermometers*, with Tanner improved thermometer cases and accessories. This apparatus was in constant use on our trips; by means of it the depth of all stations was measured, and the temperature of the water taken at bottom and surface. It proved convenient, prompt in action and was invaluable for our work. The only step necessary in rigging it in the fishing tug was to bore a hole of proper diameter in the side rail, fit a step on the deck below to hold the foot and run guy lines in two directions from the apex of the instrument. By a movement of the hand it could be turned out over the rail ready to use or brought back into a resting position. After the return of the apparatus, Commissioner MacDonald had a table constructed for calculating the readings of the register on the sounding machine, and sent the table for use in connection with the records of the summer. The sincere thanks of the party are due to Commissioner MacDonald and the United States Fish Commission for the courtesies thus extended to us.

In connection with the search for young whitefish it was of advantage to have specimens for comparison, and Messrs. Smethurst and Thompson, of Warren, Ind., were kind enough to send a number of specimens raised in their fish ponds. The approximate size of the fish at a certain age, and its general appearance, were known to us in this way. For these specimens sent gratuitously in the interests of fish culture our thanks are due the firm.

While in Charlevoix the party was in receipt of a large number of courtesies from various sources. To acknowledge them in detail would be impossible here. They helped the work materially and aroused in members of the party a friendly feeling towards the place and its residents which will not soon be lost.

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* A detailed description of the apparatus may be found in Report U. S. Fish Com., 1883, p. 57-76, plates 29 to 39.

NOTE.—I feel that an apology is due to the Commission, and no less to the various members in the party for the delay in the appearance of the final report. For this I am alone responsible and can only say that the delay has been entirely unavoidable.

LAKE MICHIGAN.

Lake Michigan stretches from 41° 40′ to 46° 5′ north latitude, and from about 85° to about 88° west longitude; its surface lies at an elevation of about 600 feet above the sea. The lake has the form of an elongated oval extending in general north and south, but the narrower northern end curves decidedly towards the east, so that the western and northern shores form with the continuous shore of Lake Huron a nearly regular semicircle. The extreme length of the lake is about 345 miles; its width is greatest opposite Grand Haven, being there 85 miles and decreasing slightly in both directions, more towards the northern extremity of the lake. At its northeastern end the Straits of Mackinac connect with Lake Huron by an open passage 8 miles wide.

Lake Michigan averages 400 feet in depth, and in some places reaches the extreme of 900 feet or more. Its area is variously given as 22,400 to 25,600 square miles, making the total volume reach 262,500,000 millions of cubic feet, according to one computation.* This enormous volume assures comparative stability of the entire mass since the total inflow, and consequently also the outflow are very small in comparison. It is impossible to measure the outflow on account of the size of the Straits of Mackinac and the variability of the flow in them, which depends upon changes in conditions of wind and weather to such an extent that at times the outlet is the seat of a powerful current setting inwards. The inflow is equally difficult to measure, since the tributaries of the lake are none of them rivers of any size, but innumerable small streams, in which the flow is not only extremely variable at different seasons, but is also in most cases entirely unmeasured.

One method of estimate yields, however, results which show clearly the minimal amount of the change even under the most favorable circumstances. The entire area of the drainage basin of Lake Michigan is given as 70,000 square miles, and according to the same authority† the lake covers 23,400 square miles of that amount, or the area of the entire basin is only three times that of the lake itself. The normal rainfall of the region is given by the tables of the U. S. Weather Bureau as from 32 to 36 inches per annum.‡ A yearly precipitation of 35 inches, which is more than the average for these places and certainly not less than the normal for the

* Not only do various authorities differ widely in the figures given, but in Reclus (90) from whom these statistics are quoted, there stands in the table, p. 250, area, 25,600. depth 870, elevation 595, while the statistical table of the appendix to the same volume (p. 464) gives the figures as 22,400, 700, and 576.

† Encyclopedia Britannica, IX Ed., article on St. Lawrence.

‡ Green Bay, 33; Milwaukee, 32.2; Chicago, 35; Grand Haven, 35.6 inches. (Report of Chief of the Weather Bureau for 1891-92, pp. 444-5.]

entire region, would mean a total of three times that amount, or 105 inches, if all of it were conserved and reached the lake. According to the investigations of Russell (88), the annual evaporation from free water surfaces, in this latitude varies from 20 inches at the head of the lake to 34 inches at its southern end, or about 27 inches for the average of this area. Deducting this and regarding the evaporation from the land and from the streams en route to the lake as *nil*, we find that the level of the lake would be raised 78 inches, or 6½ feet, by the total annual rainfall. Of course the amount of outflow in any single year is dependent on other factors as well as the rise in level by additions from the surrounding country, but on the average the amount gained by inflow and the amount lost by outflow in a single year are equal. The total change in volume during a year is then six and one-half feet; or, on the basis of an average depth of 400 feet, it would require 62 years to change the entire volume of the lake. This is certainly too much, since the loss by evaporation from the land and from streams in transit is a considerable percentage of the total. I am unable to find any definite information as to the amount lost in this way; if, however, it equals one-third the loss from free water surfaces, the deduction for an area equal to the lake would be 9 inches yearly, for double that area 18, which deducted from the figures given above would make the annual gain of the lake 5 feet. This would mean a change of *one-eightieth of the entire volume in one year*. The actual change is probably somewhat less than this. Under these conditions one may justly regard the volume of the lake as stable and as such sharply in contrast with those which obtain in those lakes which have hitherto been the object of biological investigation. In Lake St. Clair, which represents perhaps the other extreme, the inflow and outflow are sufficient to change the entire volume of water in the lake in less than six days.

Uniformity of distribution within the lake is brought about by the constant currents. These have been the subject of especial investigations by the U. S. Weather Bureau and the surface currents of the Great Lakes are given in a report by Harrington (95). From the chart of Lake Michigan in that atlas it appears that a general southerly current runs parallel to the west shore, a short distance from it, and a northerly current returns, the length of the lake, close to the eastern coast. In the southern end of the lake these currents form parts of a circular movement of which the upper cross current is below Grand Haven. Somewhat further north a broad indefinite stream sets from the western to the eastern longitudinal currents and near the upper end of the lake a whirling current surrounds the Fox and Beaver Island group. The northerly current does not seem to pass out through the Straits of Mackinac, through which the water runs in both directions at various times and under various conditions of wind and weather, but it is reflected towards the western shore. In velocity the currents vary from at least 4 to 20 miles a day, while in the extreme case it may reach 40 to 90 miles in the twenty-four hours. The movements of these currents produce then a circulation within the lake itself, and constitute an extremely important factor in the distribution of the life in the water. In addition to these regular currents there are also the irregular movements of the water due to winds and the so called tidal waves or *seiches*, both of which contribute to produce uniformity of distribution.

The lake shore presents a great diversity of physical features. At the southern end the shores are flat, sandy and entirely free from outlying

islands; towards the north they become higher, rocky and jagged while the sharp promontories are continued into extended reefs and series of islands, some few of which even attain a very considerable size. Along the lower half of the lake the shore is entire or at most faintly indented by long sweeping curves, but northward one finds numerous deep bays and sharp promontories. Two great bays face each other on opposite shores of the lake near its upper end, forming the most prominent breaks in the entire shore, and so located as to apparently balance each other. Green Bay on the Wisconsin shore is somewhat larger than Traverse Bay, its counterpart on the Michigan side, but the latter is noteworthy for its extreme depth. Both of these bays have long been famous fishing grounds, and the waters of the Traverse Bay region still continue to furnish an important part of the whitefish supply. It seemed wise to carry on the work from some central point in this region and Charlevoix was selected as the site for the laboratory. The town (see map) is located on the eastern shore of Lake Michigan, midway between Grand Traverse and Little Traverse Bay. The Beaver Island group which lies to the northwest is connected to the mainland by the "ten fathom" line, which marks out roughly the limits of an old peninsula that made this portion of the main lake a bay in former times. The northward current of the lake already referred to sweeps up through this region and circles around the islands. Though the opening between the islands and the mainland through which it runs is less than ten fathoms (18m.) deep, the path followed from the southward is marked by a sublacustrine valley of considerable depth. Stations xi and xvii which lie about in the line of this depression show a depth of 112 and 130 meters, respectively.

A pier of some length terminated by a lighthouse marks and guards the entrance to a small channel which joins Lake Michigan to Pine Lake, one of the largest bodies of water within the lower peninsula of Michigan. Midway in the course of the stream is Round Lake, a nearly circular sheet of water half a mile in diameter, the shores of which are lined by the docks and crowned by the houses of Charlevoix. Here was located the laboratory at the very edge of the water and within easy reach by boat of both the main lake on the west and Pine Lake on the east (Pl. IV). The advantages of the situation were unsurpassed for the work in hand. The numerous small lakes in the surrounding country afforded every advantage for easy comparison of life in ponds, among which were many well stocked with game fish, with life in larger bodies of water. Pine Lake, with its 96 miles of shore line furnished wide variations in depth and character of bottom, while Lake Michigan in the immediate vicinity presented areas of open water and well protected bays, shallow and deep water, with sand, cobble stone and rocky bottom. There were not wanting areas generally believed to be spawning places for the whitefish, nor fishing grounds of present and past repute, so that it was possible to find within comparatively narrow limits the factors necessary to be compared in attempting to begin the solution of the whitefish question.

I was unable to ascertain the exact length of shore line presented by Lake Michigan and hence could not calculate precisely the absolute and relative shore development. Estimates made from the government chart show that both are decidedly less than the figures given for Lake St. Clair by Reighard (p. 12). The area of shallow water is still further limited by the comparative steepness of the shore. The ten fathom line (18m.), as drawn on the chart, leaves an extremely narrow margin of

shallow water; and yet the limit set by this line is three times that of the deepest point in Lake St. Clair. The influence of the limited shore line and of the insignificant shallow littoral region on the conditions of existence will be discussed elsewhere in the report.

FLORA AND FAUNA.

In general it may be said that the number of species found in the waters of the Charlevoix region was not so great as from Lake St. Clair the year before. Reighard reports a total of 623 species from the latter place, while the total number recorded from Charlevoix was only about 500, although an equally careful search was made. The most noticeable difference, in the number of species of plants recorded, was due in part to the short time which Mr. Thompson spent in Charlevoix. Some facts of importance concerning the various groups may be recorded in this connection.

PLANTS: Of the larger plants so abundant in Lake St. Clair and in the smaller inland lakes it was evident at an early period in our work that their relative scarcity exercised an important influence in limiting the littoral fauna of the lakes. Reighard shows that the yield of the larger plants in a lake is dependent upon the amount of shallow water. To this may well be added as a second important factor the permanency of the shore, the littoral area. If, owing to storms or currents, the bottom of the shallow area is continually shifting, or if the beach is disturbed at each storm by the heavy waves rolling in from the deep water, there is little chance for the development of shore plants or such as grow in shallow water. And as a matter of fact the only considerable bed of larger plants which was encountered in Lake Michigan, occurred in the sheltered High Island Harbor. (Pl. V, station xv.)

These two factors serve to explain the limited development of the larger plants in the Charlevoix region, and the casual visits paid by members of the party to inland lakes in the vicinity which resulted in the discovery of much crowded masses of shore and bottom vegetation in those smaller and shallower lakes, go to strengthen the force of the conclusion. I do not feel sure that the deficiency in the group of filamentous algæ noted by Mr. Thompson in his report appended to this paper, can be explained on the same ground alone, but certainly these factors are of some importance in this connection also.

Among microscopic plants Mr. Thompson calls attention also to the entire absence of Desmidiæ* from the waters of Lake Michigan and also from those of both Round and Pine Lakes. The Diatomaceæ were, however, extremely abundant, both in species and in individuals, and were according to Mr. Thompson's observations most plentiful in the deep towings. This may be due possibly to the great transparency of the water. A more detailed account of the plants, together with a list of the species determined and data on the distribution of various forms may be found in the report of Mr. Thompson (Appendix I, p. —). The amount of material collected is actually very large if it be remembered that Mr. Thompson was

* Two species of rare occurrence were recorded at the laboratory during the summer.

called in at a late date to fill a vacancy in the party, that he was able to be with us only a few weeks, at the end of our stay in Charlevoix, and that he had to contend with numerous difficulties apart from the brief time at his disposal.

In addition to those found by Mr. Thompson, the following species of microscopic plants were recorded at the laboratory during the summer.

Anabaena flos-aquæ Kg.
Cocconeis transversalis Greg.
Cyclotella operculata K.
Eurastrum inerme Lund.
Gomphonema acuminatum Ehr.
Merismopidia convoluta.
Navicula major K.
maxima.
producta S.
Pediastrum beryanum.
Stephanodiscus niagare E.
Treyblionella scutellum Smith.

ANIMALS: The following notes on various groups of animals are deserving of special mention or of particular explanation in this connection. A list of the groups represented in fresh water, together with the common names of these groups is given by Reighard (p. 16).

Protozoa: A very full report on this group by Dr. C. A. Kofoid is appended (p. –). These forms constitute one of the chief elements of the plankton, furnishing as they do the simplest animal food and being one immediate source of food for the smaller crustacea which in turn become the prey of various fishes, they are an exceedingly important factor in fish economy. This was pointed out by Ryder (81), who, however, regarded the Protozoa only as an *indirect* source of the food of fishes. They are indeed important from this standpoint alone; but the work of Peck (94) establishes the value of the Protozoa and Protophyta of the plankton in one case at least, as a direct source of food supply also. Thus far no fresh water fish is known to have similar habits, but investigations should be made as to whether the same is not true to some extent at least of our lake herring. It is interesting to note the confirmation in Dr. Kofoid's report of the absence of a littoral zone, and the freedom from shore mixtures of Lake Michigan plankton, as shown by a study of the protozoan representatives. The number of species which are characteristically limnetic is large here, being eighteen for Lake Michigan, as compared with thirteen in Plöner See and seven in Lake St. Clair. These forms are widely distributed and none of the species seem to be exclusively characteristic of this region. The list of species would have been considerably extended, except that our attention was confined chiefly to a study of the plankton, while collections from the shores and from the inland lakes were obtained only casually.

Coelenterata: No fresh water sponges were found in the lakes at Charlevoix. Both the white and the green *Hydra* were met with occasionally in bottom tows. Their comparative rarity is unquestionably due to the scarcity of vegetation to which they ordinarily attach themselves, since in the collections brought back from the inland lakes north of Charlevoix by Dr. R. H. Ward they were exceedingly numerous. In some bot-

tles from that region the white *Hydra* was found in such numbers as to constitute the bulk of the material in the entire haul.

Worms. *a.* **Turbellaria:** (Non-parasitic flat worms.) The following species were found on algæ collected from the old channel, Round Lake:

Mesostoma viviparum Silliman.	*Microstoma lineare* Or.
Vortex sp.	*variabile* Leidy.

An unidentified form occurred once or twice in the bottom tow and four vials of specimens were set Dr. W. McM. Woodworth for identification. He reports two species found in the vials, *Vortex armiger* O. Schmidt, and *Mesostoma* n. sp. described later in this report together with other data on this group. (App. IV.)

b. **Parasitic Worms:** A total of 1410 parasites were obtained from 115 specimens representing eighteen species. These included *Coregonus artedi, C. clupeiformis, C. prognathus, C. quadrilateralis,* and *Salvelinus namaycush.* The whitefish and trout were in some cases badly infested with tapeworms and *Echinorhynchi*; but on the average there were fewer parasites than in the fish from Lake St. Clair examined the year before. A single free specimen of *Mermis* and a few of *Gordius* were taken from Round Lake and Lake Michigan respectively.

c. **Oligochaeta:** These worms were not so frequently met as in the Lake St. Clair work. A small collection, comprising 6 vials of alcoholic specimens, was sent by Dr. Eisen for identification. The relative scarcity was due no doubt to the scanty littoral and bottom vegetation, on which they are commonly abundant and from which certain species were collected in large numbers in Lake St. Clair.

d. **Hirudinea:** The leeches were represented by several very large species, and numbers of other forms, all of which are in the hands of Professor Raphael Blanchard, who will make a report on them in detail. One very interesting striped form, *Ichthyobdella punctata* Verrill, was present in large numbers on the fish lifted in gill nets. They attack mostly whitefish and are found in abundance. Thousands are strewn over the nets, boxes, and even the deck itself when the seine is hauled in.

e. **Bryozoa:** In dredgings made on the Middle Ground, Traverse bay, at a depth of from 23 to 36 m., a considerable number of colonies of these forms were collected. With them were dredged scanty filamentous algæ. The Bryozoa were submitted to Dr. C. B. Davenport, of Harvard University, who very kindly determined them. He reported that *Paludicella Ehrenbergii* van Ben. and *Fredericella sultana* Blumenbach, were abundantly and typically represented in the mass sent him, and that the stocks were evidently living when found. *Cristatella mucedo* Cuv. was represented by a part of a statoblast only which had undoubtedly floated down from a higher level. The first two species are an interesting addition to the deep water fauna of the lakes, and I think the deepest recorded occurrence of Bryozoa in fresh water. Agassiz ("Three Cruises of the Blake") records marine forms from a depth of nearly 900 m.

The forms mentioned above were also obtained from "honey comb" rock brought up in gill nets from about the same depth in the vicinity of the reef between Charlevoix and Beaver Island. (See map, station ix).

f. **Rotatoria:** These forms constitute an important part of the microscopic fauna of the lakes. One hundred and ten species were reported in 1893 from Lake St. Clair. Last summer only ninety-four were found in the entire Charlevoix region, and but fifty-eight of these occurred in Lake

Michigan or in the immediately connecting waters of Round and Pine lakes. The limnetic (pelagic) species were well represented, being in number only three less than the true limnetic species of Lake St. Clair, but the absence of shore and bottom vegetation precludes the development of the large number of littoral and bottom forms found in smaller and shallower lakes. Thus only eight bottom species in all are reported from Lake Michigan. Mr. Jennings, in his report on these forms, printed as an appendix, calls attention to some biological facts of great interest, such as the accumulation of the Rotifers near the surface in the day time and the rapid variations in the number of individuals and in the ruling species of the plankton. Out of the ninety-four species recorded twenty are new to Michigan and one new to science.

Crustacea: Of this class the following orders were represented in material obtained at Charlevoix. These forms constitute the most important element of fish food and are found in large numbers in the shore, the bottom and the limnetic faunæ.

a. **Cladocera:** Between twenty-five and thirty species of these forms were taken at Charlevoix. They were most abundant in the smaller inland lakes, no less than twenty species being recorded as the result of a half day trip to Twenty-Sixth lake. In the larger lakes they form a less important element of the faunæ. No detailed report on the number or frequence of these forms has yet been made.

b. **Copepoda:** A special report on this group has been published (Marsh, 95), from which a few quotations are made here. "From the standpoint of the pisciculturist, perhaps no class of animals outside the fishes themselves is so important and interesting as the Entomostraca. It is a well known fact that these minute crustacea form the entire food material of the young of some of our most important food fishes, and in many cases constitute a large part of the food of the adults."

With reference to the representatives of this group in the Charlevoix region, Marsh says (p. 4), "It is interesting to note the greater richness of the copepod fauna of our lakes as compared with those of the continent of Europe. Zacharias finds seven species of copepods belonging to the Cyclopidæ and Calanidæ in the Plöner See. In Lake Michigan there are nine, and that includes no littoral species; in the two lakes on Beaver Island there are eight, in Pine Lake nine in Round Lake eleven, in Intermediate Lake eleven, and in Lake St. Clair sixteen. The larger number in Lake St. Clair is probably explained by the fact that, being very shallow, it has the species of the smaller bodies of water and of the stagnant pools, and in addition, because of its connection with the Great Lakes, has also their limnetic species.

"Pine Lake is peculiarly poor in its number of species; this is strikingly apparent when we compare it with Intermediate Lake. Pine Lake was very thoroughly examined, and it is likely that we are acquainted with all the species occurring there, and yet the number is only eight. All the collections from Intermediate Lake were made in one day by a party which went down from Charlevoix and remained only a few hours, and yet the number of different forms is eleven. Intermediate Lake seems to be an usually rich collecting ground, for, with the exception of Lake St. Clair and Round Lake, no other lake shows such a large number of species, and both Lake St. Clair and Round Lake have been very thoroughly explored. Moreover, in the case of Round Lake, several of the species may be considered as immigrants from Lake Michigan."

In a letter of recent date Professor Marsh says:

"There are no characteristic species in Lake Michigan at Charlevoix, as the fauna of the Great Lakes is, so far as I can make out, identical. Lake St. Clair has some stagnant water forms in addition to those commonly found in the lakes. From the stations about Charlevoix I have 17 determined species. There was besides at least one species of *Ergasilus*, one or more of *Canthocamptus*, and the parasitic forms which I have not worked out at all."

In the report referred to above are given a table of distribution and keys for determining the various species in the groups which are found in Michigan. For further details the original should be consulted.

c. **Ostracoda** are not uncommon in Round and Pine lakes, they are not, however, sufficiently numerous to be an important element of the plankton. The species obtained have not been determined as yet.

d. **Amphipoda:** There are two species of amphipods which are characteristic in their distribution. *Hyallella dentata* Smith is found in large numbers along the shores of Round Lake (Pine Lake?), and the inland lakes. It was not reported from Lake Michigan though it may well be present in the immediate vicinity of the shore. In deep water its place is taken by *Pontoporeia Hoyi* Smith which came up in every haul of the dredge, and was frequently present in enormous numbers. This species forms one of the chief sources of food for various species of whitefish. (See p. 21.)

e. **Podophthalmia:** The Stalk Eyed Crustacea are represented by shrimp-like forms and by the crayfishes. A single species of the first, *Mysis relicta* Lovén, occurs in Lake Michigan in deep water; from 24 to 130 m. (the deepest station) it was abundant everywhere that we tried the dredge. On one occasion a bottom tow with the runner net brought up a large number of individuals which were kept alive in a pail for a time, but soon died, perhaps on account of the rise in temperature of the water. They are among the most transparent and active of fresh water Crustacea and yet furnish much the largest percentage of whitefish food afforded by any one species (see tables p. 21). For themselves they appear to rely largely upon the Copepods of the plankton for food. In spite of their abundance we did not take a single immature form in our nets.

Two species of crayfish, *Cambarus propinquus* Ger., and *C. virilis* Hagen, were found both in the main lake, and in the connecting waters of Round and Pine lakes These species came up in large numbers on the gill nets of the fishermen and were taken in the trawl as well as caught in shallower water along shore. They furnish an important element of the food of the larger fish.

Hydrachnidæ: The water mites seem to be very abundant at Charlevoix. With reference to the group Dr. Wolcott reports:

"Of Hydrachnidæ, to which very careful attention was devoted, owing to personal interest in the subject, 43 species were taken belonging to 16 genera; of these 23 species and 4 genera were not represented in the collection from Lake St. Clair. Numerous specimens of a mite identified in the previous collection as a species of Oribatidæ, were also obtained."

Insecta: A disappointingly small number of forms both in species and individuals was found in Charlevoix waters. The absence of the littoral and bottom vegetation, which in Lake St. Clair afforded shelter and support to a host of larvæ, evidently accounts for the deficiency in this respect. That this was clearly the cause became apparent on the cursory

examination of the smaller inland lakes of the region which sheltered among the littoral and bottom vegetation countless larvæ. No attempt was made to collect or include in the list these forms from the smaller lakes. With the scarcity of insect larvæ goes hand in hand the absence of those fish which depend largely or entirely upon these forms for food, and which were abundantly found in Lake St. Clair. Dr. Wolcott listed 77 species from Charlevoix, determined as follows: Odonata 9, Ephemeridæ 7, Perlidæ 1, Phryganidæ 13, Hemiptera 6, Coleoptera 18, Lepidoptera 3, Diptera 20, and adds concerning them "To these must be added a number of species of aquatic habits during a whole or part of their existence which were, however, collected not in towings or dredgings, but only in the adult state; these are sufficient to bring the total list of aquatic forms observed up to considerably over a hundred. It was to be expected that the experience of the previous year at Lake St. Clair would have rendered possible the collection of a still larger number of species, but the conditions were to some extent unfavorable. Both Pine and Round Lakes, deficient as they were in vegetation, exhibited an equal deficiency in the number of species of insects, although the latter were present in considerable numbers wherever vegetation occurred, as it did at some points. Shallow pools along the shores of Pine Lake supported an abundant fauna, but since they hardly came within the territory embraced in the scope of the party's work, no extensive collections were made from them."

"Dredgings from Lake Michigan in moderate depths, especially when over beds of *Chara*, etc., brought to light a considerable number of insects which were in no wise peculiar. Very interesting, however, was the occurrence on one occasion of a species of *Nemoma*, one of the Perlidæ, in the deeper parts of the lake in the vicinity of Charlevoix."

Mollusca: This group was very thoroughly studied by Mr. Bryant Walker whose report is found in appendix V. I would call attention here to his remarks on the scarcity of the large bivalves which are an unimportant element of fish food and the universal abundance of the smaller forms, both univalves and bivalves, which constitute so important a factor in the food supply of the lake fish. (See tables p. 21). While Mr. Walker calls especial attention to the large number of forms found in beds of *Chara*, it is equally true that the surface of the boulder covered areas of bottom, so plentiful a short distance off shore in that part of Lake Michigan appears peppered with small snails; and together with crayfish they constitute the chief animal forms taken in dredgings in this region. These univalves subsist in large part on the minute algæ derived from the plankton, while the bivalves are entirely dependent upon this source for their food supply. Here there is then but one intermediate stage between the life of the plankton and the whitefish. Mr. Walker also notes the poverty of the molluscan fauna in Pine Lake. Details with reference to the various species and their distribution are to be found in the appendix. It is not too much to say that no group was more thoroughly and accurately worked up than this and the importance of these data for the whitefish investigation is apparent on examination of the tables of whitefish food, already mentioned.

Vertebrata: Water birds are not as common on the lake as they were at Lake St. Clair and turtles were found only in the smaller inland waters. Amphibians were not noticed in Lake Michigan at all and were rare in the other waters examined. Only a single specimen of the "mud puppy" (*Necturus maculatus* Raf.) was found, and that in the old channel

between Round and Pine lakes. This species is extremely abundant in Lake Erie and Lake St. Clair and destroys an enormous number of white fish eggs, the Necturi taken in the Detroit river in the fall being gorged with the freshly laid eggs. The apparent rarity of the form further north is hence fortunate.

The following list shows the species of fish taken in various places as indicated: C, old channel between Round and Pine lakes; M, Lake Michigan; P, Pine Lake; R, Round Lake, (Pl. IV). The list is by no means complete since particular attention was paid only to the important food fish and to smaller forms captured by chance in the search for young whitefish. The identification of the smaller forms was made by Mr. Jennings, while we worked together on the various species of *Coregonus*. We had determined the Lake Michigan "Long Jaw" as an undescribed species, and it was only in the fall that on receipt of the paper by Smith (94) I saw it was identical with his species *C. prognathus*.

Scientific Name.	Common Name.	Locality
Ambloplites rupestris (Raf.)	†Rock bass	R.
Ameiurus melas (Raf.)	†Bullhead	C.
Catostomus teres (Mitch.)	†Sucker	P.
Coregonus Artedi LeS.	†Lake Herring	M.
clupeiformis (Mitch.)	†Whitefish	M.
quadrilateralis Rich.	†Menomonee	M.
(?) *tullibee* Rich.	Long Jaw (?)	M.
nigripinnis (Gill.)	†Blackfin	M.
prognathus H. M. Smith	†Long Jaw of L. Michigan	M.
Cottus Richardsoni Ag.	*Miller's Thumb	M. R.
Etheostoma nigrum Raf.	*Sand Darter	M. R.
caprodes Raf.	*Log perch	M.
Eucalia inconstans (Kirtland)	*	M. P.
Lota lota (L.)	†Lawyer	M. P.
Micropterus dolomieu Raf.	Small mouth Black Bass	R.
Notropis deliciosa (Gir.)	*	C.
megalops (Raf.)	†Common Shiner	R.
Percopsis guttatus Ag.	*	M.
Perca flavescens (Mitch.)	†Perch	R.
Salvelinus namaycush (Wal.)	†Lake Trout	M.

Names after Jordan, Manual of the Vertebrates, fifth edition, Chicago, 1890.

Half a dozen species of young fish or small forms are yet unidentified. If these and the fish taken in the smaller inland lakes were both added the list would be considerably extended.

The food relations of the various forms listed in the foregoing can not be given at present in more than general terms. For a discussion of this subject and a valuable table expressing some of these relations in synoptic form the reader is referred to Reighard (95, pp. 23 and 24).

One striking faunal peculiarity appears on examination of the preceding account of the various groups to be generally characteristic not only of Lake Michigan, but also in great part of Round and Pine lakes. It is the absence of the littoral flora and fauna. The abundance of life which characterized the shore region on Lake St. Clair is here entirely lacking.

* Taken in trawl in various localities.
† Examined for food and parasites.

It may well be that all other deficiencies are due to the absence of littoral vegetation, the reasons for which have already been discussed. At any rate, the barrenness of the littoral zone eliminates from the question of the food supply of this region one element which in Lake St. Clair was of extreme importance.

Mention has been made of the limited bottom vegetation and of the absence of certain forms of animal life ordinarily found in connection with the plants of the bottom. This matter will be discussed further in another part of the report. Here may be recorded merely the limited development of this source of food supply in this part of Lake Michigan.

To one small group of forms, the various species of whitefish, particular attention was paid and the results of this study are embodied in a special section of this report.

THE WHITEFISH.

Eight species of *Coregonus* are known to occur in the Great Lakes; they are the common or true whitefish, *Coregonus clupeiformis* [Mitch.], the "blackfin" *C. nigripinnis* [Gill], the "long jaw," *C. prognathus* H. M. Smith, the lake herring or cisco *C. Artedi* Le Sueur, the tullibee or mongrel whitefish, *C. tullibee* Richardson, the Menomonee whitefish, *C. quadrilateralis*, Richardson, the "Soo" whitefish or whiting, *C. labradoricus* Richardson, and the Lake Michigan cisco or the lake "mooneye" *C. Hoyi* [Gill]. The last four from their rarity or small size, are of little importance commercially, and only one of them the Menomonee whitefish, was seen at Charlevoix. All of the first four, however, were obtained there, and the first three were the object of especial study They are the species ordinarily marketed and are sold indiscriminately under the name whitefish, although the fishermen distinguish them easily. In fact the "long jaw" was constantly picked out for us as a distinct form by the fishermen, and after numerous efforts to make it fit the description of some known species, Mr. Jennings and I were forced to admit its distinct character. Early in the fall the paper by H. M. Smith (94) fell into my hands, and the identity of the Charlevoix form with the new species described therein was at once apparent.

The habits of the whitefish are only meagerly described in our literature. Since Milner (74) nothing more than scattered details have appeared, and a good account of the biology of this group is yet to be written. The work at Charlevoix was not extensive enough to add greatly to our knowledge; there are, however, some observations of value made there which may be recorded in this place.

The horizontal distribution of the four species is, so far as our observation extended, uniform; but the vertical limits seem to be very different. This is mentioned in the work of Milner, but our own observations, and also the reports of the best fishermen, seem to indicate even a more definite location for each species. It seems that the lake herring is a surface fish and is taken in gill nets only near the surface; the true whitefish is caught in water as shallow as twenty feet, but is most common between twelve and twenty fathoms. The long jaw is rarely found in twelve fathoms; it is, however, abundant in depths of from twenty to twenty-five fathoms,

but does go somewhat deeper, while the blackfins are rarely met in less depth than forty fathoms. This vertical distribution is so definite and so well known that the catch of a gill net at any given depth may be predicted with considerable accuracy. It is the summer range of the fish and is modified at the spawning season. One naturally suggests temperature as the ruling cause for this vertical limitation of distribution, since, as will be seen later, the food of these various species has a much wider vertical range than the species itself, and since the accounts given by fishermen of the winter limits of the species correspond in general to the temperature changes. This matter should be the subject of special study during the entire year in connection especially with accurate and extended observations on the temperature of the water.

In the next place our entire knowledge of the food of the young whitefish, and in fact all other information with regard to the fish in the first year of its life, depends upon inference. Forbes (82) has furnished the only experimental information on this subject. He placed several thousand whitefish fry in a tank fed by Lake Michigan water and supplied them with an abundance of organisms obtained from the lake by a tow net. From this, which is identical with the plankton mentioned elsewhere in this report, the fry selected chiefly small Entomostraca. Forbes says (p. 781), "The entire number of objects appropriated by the sixty-three fishes [out of 106 examined] was as follows: *Cyclops Thomasi*, ninety-seven; *Diaptomus sicilis*, seventy-eight; *Anuræa striata*, twenty-nine; *Daphnia hyalina*, one." From this he concludes that "the two species of Copepoda, *Cyclops Thomasi* and *Diaptomus sicilis*, are certainly very much more important to the maintenance of the whitefish in the early stage of independent life than all the other organisms in the lake combined." Interesting and valuable as these experiments are, it should be noticed that the evidence is not complete. The fact that in captivity the fry eat these two species in particular is no proof that in nature their food is the same. In the Agassiz Marine Laboratory at Newport I have easily reared young toadfish, a pure bottom fish, on the small crustacea of the plankton. It would be hardly safe on this evidence to regard the young toadfish as normally plankton eaters; the probability is that the natural food of the young was substituted by nearly related forms of *approximately the same size*. Forbes notes that the *Cyclops* was the smallest of all the Entomostraca in the plankton and that the *Diaptomus* was the next in size. This is also the order of preference expressed by the whitefish fry as shown by the number of each species eaten. Reighard (94, p. 40), expresses the opinion that the whitefish fry are more probably bottom feeders. If so, their natural food will then be some of the small bottom crustaceans of no doubt approximately the same size as the two just mentioned, most likely closely related species, but not these forms which are limnetic in character. The nature of the first food of the whitefish fry was clearly demonstrated by Forbes in the discovery of the pharyngeal teeth, which are wanting in the adult, and which point unmistakably to the carnivorous habits of the young. They prey undoubtedly on the Entomostraca; the exact species on which they subsist, however, yet remain to be established.*

*The matter can only be determined experimentally and I am informed by correspondence that the Michigan Fish Commission, during the past spring, has carried out a series of experiments by planting the fry in boxes supplied with gauze gratings. The boxes were anchored in favorable localities at the surface and near the bottom and a certain number of the fry taken periodically and examined for food. The results of these experiments may well be awaited with great interest.

It was the hope of those interested in the work at Charlevoix that some of the young whitefish hatched in the spring might be caught, and thus evidence furnished as to the food and habitat of the fish during the first year of its life. At the very beginning of the stay an assistant was set to scouring the shores, inlets and shallow places in order to catch all the young fish which could be found; a large number of different species was collected, but none of the whitefish family. A trawl was constructed and used on all of our August excursions into Lake Michigan with the fishing tug. It was tried in waters of various depths and over all bottoms where it could be run and was successful in obtaining a number of species of small fish from these localities (see list on page 17), but no whitefish. The bottom of Lake Michigan in the Charlevoix region is not very favorable for the use of a trawl, as even the stretches of sandy bottom are strewn with occasional boulders, and in the course of our work the trawl was first lost and recovered only after a long search, and finally on the following day torn to pieces. In future work a fine meshed silk gill net would, I believe, be more likely to succeed in catching the young whitefish.

During severe storms young fish are thrown up on the beach of Lake Michigan near Charlevoix, and from this source we obtained immature specimens of the lake herring, of the Menomonee and probably of the long jaw, but none of the true whitefish. The specimens were from three to five inches long and were as small as any ever obtained there. They were probably fish which had been hatched in the spring of that year. The absence of young whitefish in spite of the large catch of the adult fish at this point shows either that the young are more limited in their distribution than the adult and hence are not found at this point, or that they live deeper than the young of other species mentioned and thus are not affected by the wave action in time of storm. Some account of the food of the adult whitefish is given by Milner (74, p. 44) and Smith (74). The number of specimens reported was small, and also the importance of each element in the total amount was left unnoted; furthermore the food of the allied species has received no attention. Hence it seemed wise to devote careful attention to this point and ascertain as exactly as possible the character of the food and amount of each element in it for each of the species of whitefish. A large number of stomachs of whitefish were examined and the results of this study are expressed in the following tabular forms. The specimens examined were from widely separated fishing grounds, representing more than the limit of territory covered by the map of the Charlevoix region given in this report (Pl. V). In the identification of the species of food animals, all the members of the laboratory force participated, and the estimated percentages were similarly controlled so that every effort has been made to reduce the error of such observations to a minimum. The first table presents the results of observations on the food of the true whitefish.

Name of food animal.	Specimens of *Coregonus clupeiformis* examined.														Av.
Mysis relicta Lovén	95	70	----	70	5	----	5	----	----	35	----	----	----	----	20
Pontoporeia Hoyi Smith	----	5	30	----	----	95	85	85	65	----	80	70	90	*	43
Eurycercus lamellatus	----	----	----	(*1*)	----	----	----	----	----	----	----	----	----	----	----
Total Crustacea	95	75	30	70	5	95	90	85	65	35	80	70	90	*	63
Limnæa catascopium Say	----	----	----	----	----	----	----	----	----	----	----	----	----	(*10*)	----
sp. (*juv.*)	----	----	----	----	----	----	----	----	(*1*)	(*4*)	----	----	----	----	----
Physa sp. (*juv.*)	----	----	----	----	----	----	----	----	----	----	----	----	----	(*3*)	----
Planorbis parvus Say	----	----	----	----	----	----	----	----	----	----	----	----	----	(*10*)	----
Amnicola limosa Say	----	----	----	----	----	----	----	----	----	----	----	----	----	(*8*)	----
lustuca Pils.	----	----	----	----	----	----	----	----	----	----	----	----	----	(*2*)	----
porata Say	----	----	(*1*)	----	----	----	----	----	----	----	----	----	----	----	----
Valvata sincera Say	----	----	(*5*)	5	----	----	----	----	----	10	----	5	----	10	2
tricarinata	----	----	----	----	----	----	----	----	----	----	----	(*1*)	----	(*1*)	----
Sphærium striatinum Lan.	----	----	----	----	55	----	----	----	----	----	----	(*1*)	----	(*3*)	4
n. sp.	----	----	(*1*)	----	----	----	----	----	20	(*1*)	----	5	----	10	3
Pisidium (several species)	(*3*)	5	60	15	35	2	1	----	10	35	(*1*)	10	----	60	16
Total Mollusca	*	5	60	20	90	2	1	0	30	45	*	20	0	95	26
Chironomid larvæ	*	8	5	5	*	3	8	10	*	*	15	*	5	----	4
Hydrophilid larvæ	----	----	----	(*1*)	----	----	----	----	----	----	----	----	----	----	----
larvæ	----	----	----	----	----	----	----	----	----	----	2	5	----	----	----
Total Insecta	*	8	5	5	*	3	8	10	*	*	17	5	5	----	5
Small fish	----	12	----	----	----	----	----	----	----	15	----	----	----	----	2
Fish eggs	----	----	----	----	----	----	----	----	----	----	(*6*)	----	----	----	----

1, 3, 5, etc. = percentage of each form in total food mass estimated from volumes.
(*1*), etc. = number of individuals found constituting always less than 5%.
* = trace, or a few specimens, constituting a small uncertain amount or less than 1% of total.

In addition to objects mentioned small brown stones were very common, and in instances formed one-fourth or one-fifth of the total mass; they were not included in the percentages as they did not seem to be a part of the food proper. A trace of filamentous alga (*Cladophora*) was frequently encountered in the stomach contents where its presence was apparently accidental. A considerable number of stomachs were examined which were empty, or in which digestion had proceeded so far that the computation of percentages was uncertain. Both classes are omitted from the table, although so far as could be seen the latter would not have modified the results appreciably.

Summarizing the results given in the table it will be seen that among these fourteen specimens

Pontoporeia constitutes from 0 to 95 % of the total food, averaging 43 %.
Mysis " " 95 to 0 " " " " " " 20 %.

The two forms seem not to be found together in considerable amounts, but the presence of the one indicates the absence, or at most, presence in a trace of the other, making thus the average percentage of crustacean food 63. This alternation seems to indicate a difference in the distribution of the two forms so that the whitefish are likely to find one or the other, but not both on the same feeding ground.

This element is never entirely absent, and, on the other hand, forms two-thirds or more of the entire food mass in ten cases out of fourteen. It

is clearly not only the most important element of the food, but is on the average more prominent than all others put together.

Pisidium	constitutes	from	0 to 60 %	of the	total	food,	averaging	16 %.
Sphærium	"	"	0 to 55 %	" "	"	"	"	7 %.
Valvata	"	"	0 to 10 %	" "	"	"	"	2 %.

Other species of mollusks are present in varying small amounts, making the total amount of food furnished by these animals on the average 26%. In three cases out of fourteen this was the bulk of the entire food, and in two instances it was entirely lacking.

The insect larvae, chiefly Chironomids, are a small though comparatively constant part of the food, constituting at most only 15%, and on the average about 5% of the whole. The two cases in which small fish were found, suffice to make this element average 2% of the whole. Whether it is constantly even such a small percentage of the total could only be told by a much greater number of cases; but the percentages of other elements are probably correct within a small amount. It is interesting to notice that only one of the fourteen fish had enjoyed such a mixed diet that no element predominated in its food.

The considerable part played by the mollusks and insect larvæ, both of which are strictly bottom forms, shows that the common whitefish is to a large extent a bottom feeder. This view is strengthened by the down pointed sucker-like mouth of the fish as well as by the presence in the stomachs of numbers of small stones, which were undoubtedly snapped up with some morsel of food.

Of the six specimens of the long jaw (*C. prognathus*), which furnished stomach contents sufficiently undigested to be estimated, five contained *Mysis relicta*, constituting respectively 95, 95, 95, 98 and 100% of the total mass, or an average of 97%, while in the sixth *Pontoporeia Hoyi* was equally abundant. No other recognizable object was present in any of the fish examined. Smith (94, p. 10), in his description of this new species, is able to give only conjectural information as to its food. The stomachs examined do not bear out his surmise that "its larger mouth and more powerful jaws indicate a somewhat wider range of food than is possessed by the common whitefish." Nor do I think that such is the case; its deeper habitat favors a more simple diet since the fauna of the region is more limited in number of species. Again, the anatomical characters referred to find their explanation equally well in the hunting habits of the fish; its food is captured in motion and not on the bottom, hence the strictly bottom forms in the food of the common whitefish, the mollusks and insect larvæ, as well as those accidental inclosures, algæ and stones, are entirely wanting. This difference in the mode of life of the fish, which seems to me adequately indicated by the facts given, is of importance in another connection, as will be seen later.

Only two specimens of the blackfin afforded identifiable stomach contents; *Mysis relicta* was here 95 and 99% of the total amount; one of these specimens yielded a single individual of *Diaptomus* sp., whose presence was perhaps accidental; otherwise nothing was recognized.

Collections of parasites were made from all the species of whitefish obtained at Charlevoix; occasionally individuals were found badly infested with a species of *Echinorhynchus*, but as a whole these fish were very free from parasitic infection.

The question of the decrease of the true whitefish has attracted much attention during the last ten or fifteen years, and the cause has been a matter of considerable dispute. I believe we are in position to offer positive evidence on the question. The fact of the large decrease in the whitefish catch since 1880 is, I think, unquestioned at present, although there is evidence of yearly fluctuations in the catch both before and since that time. The present scarcity of the fish may be due (1) to disease, (2) to scarcity in food supply, (3) to migration, (4) to the crowding out or supplanting of the true whitefish by some other species, (5) to over catching. The first may be dismissed without further discussion since any disease widespread enough to cause such a result would surely have come to the notice of fishermen.

The three most important elements of the whitefish food are *Pontoporeia*, *Mysis*, and the small mollusks. At nearly all of the stations where hauls were made with the vertical plankton net (see Pl. V) the dredges and other nets were also used. Among their contents the three forms just mentioned were the most common of all objects; so much so indeed that their absence in rare cases was noteworthy. Thus, for example, in my notebook is entered for station ix: "Dredge out 5 minutes. Noteworthy—*Mysis* wanting, mollusks almost, very few *Pontoporeia*; according to Capt. O'Neil this point (middle of w. side reef) has *no* whitefish." The immediate food of the whitefish is present at nearly all points and in large quantities, hence the decrease in whitefish supply can hardly be due to this cause. So far as migration is concerned, it might be invoked to explain a deficiency in the catch in a single locality, but statistics now at hand show the decrease to be general and not confined to a single region.

In his recent paper Smith (94, p. 11) suggests an interesting theory as to the possible cause of the disappearance of the common whitefish; namely, that it has been crowded out by the long jaws. It is a well known biological fact that in the struggle for existence one species is supplanted by another more favored form which takes possession of its home and food supply and literally crowds it out of existence. This is most likely to occur between closely related forms in circumscribed areas, and it would appear at first thought as if this were a very probable instance of such supplanting. It is also a curious fact that the same idea occurred to me in Charlevoix and was discussed with at least one member of the party, Mr. Bryant Walker, before the appearance of Smith's paper. In the course of further study, however, I became convinced that the idea was untenable and that the competition between the two species was more apparent than real; in other words that this could not be the cause of the diminishing whitefish supply. The reasons for this conclusion may be given briefly. In the first place the range of the two fish is radically different; long jaws are rare at twelve fathoms where the best catches of whitefish are made, and conversely whitefish are not found at the depth of twenty to twenty-five fathoms where the long jaws are most abundant; nor could I find evidence of any change in range of the species during the last twenty-five years, if one will accept the testimony of the best fishermen. Again, the food of the two forms is somewhat different, as noted above, and more still the place and manner of feeding I have already pointed out that the whitefish is probably a bottom feeder, and that the long jaw is not, but obtains its food more probably free in the water. Furthermore, if crowding out were the cause, the grounds

formerly occupied by whitefish must now be preempted by long jaws. It can be positively stated, I think, that such is not the case. As is noted elsewhere in connection with the plankton studies, we examined especially those regions which had been good whitefish grounds, but now yielded little or no catch. In all of the places whitefish food was plentiful, though the grounds were now practically deserted by *all* fish, and many of them were much too shallow for long jaws.

The apparent coming in of the long jaw and the increase in its catch are really due to very different causes. The failure of the shallow whitefish grounds forced the fishermen little by little to move their nets into deeper waters and so gradually to increase their catch first by the addition of long jaws and then by the still deeper living blackfin. These two species are only apparently new arrivals, and their supposed increase at the time of the whitefish decrease is due merely to changed methods of fishing. In this connection it is interesting to notice the testimony of Capt. John O'Neil of Charlevoix, that the long jaws themselves are less frequent in Traverse Bay than formerly, that they are smaller in size and more scattered.

We are thus forced to the conclusion that the decrease in the whitefish supply can have no other cause than overcatching. This is not the place to discuss good and bad methods of fishing or remedies for the trouble. Our investigations point unmistakably to the cause of the depletion in the whitefish supply; it is the removal from the lakes of a larger number than can be replaced by natural processes and than has been successfully returned by artificial hatching. Greater results from the latter methods depend upon a better knowledge of exact conditions in the lakes, and to aid in this has been the object of our studies.

SOURCE OF FOOD SUPPLY.

The question as to the food of the whitefish and the amount of the supply at any point, or, expressed in other terms, the actual fish supporting power of any region is not determined by a single element. The number of *Mysis* and *Pontoporeia* in any given area does not determine the fitness of that region for raising whitefish.

Not only must the present supply of whitefish food be large, but the region must be capable of maintaining the supply constant in spite of the inroads made by the fish, else the food would soon be exhausted and the fish starved to death. The further test must be then made as to the capacity of the place to furnish these food animals with sufficient nourishment for rapid multiplication. Thus we are taken back step by step through the entire series of biological interdependence to the primitive food supply, which must always be plant life, since that alone has the power to manufacture living matter out of the simpler substances taken from earth, air and water. It is then clear that the entire series of biological relations must be worked out, and with each step will come new light on the subject.

The question of the source of the food of the lake fish brings us to consider first in brief the peculiar characters of these bodies of water in comparison especially with the inland lakes. On the more extended trips into Lake Michigan, which were undertaken with a view to obtaining evidence on the distribution of life in the lake, the contrast between this and an inland lake, or even Lake St. Clair, became very apparent. The most

striking peculiarity was the entire absence, in the part of the lake examined, of the larger plants. The shore plants and rushes which in Lake St. Clair formed several distinct zones (Pieters, 94) along the margin of the lake, were either entirely absent or present in rare instances. The shallow part along shore, or lake terrace (Reighard, 94, p. 13) is very narrow at this point and subject to considerable change by the frequent storms; to this is due no doubt the absence of shore vegetation, and there are out in the lake, beyond the shore terrace, no areas shallow enough to permit the growth of such vegetation. Not only were the littoral zones bare of plants but the bottom also. The fields of *Chara* which carpeted the bottom of Lake St. Clair so densely that Reighard (p. 15) compares them to a thrifty field of clover, were almost never found. Only once in the sheltered High Island harbor was there a shallow area covered in this way with *Chara*. Elsewhere stretches of bare sand alternated with equally bare rocky bottoms or with areas of huge cobblestones. The stones brought up in the dredge were frequently covered with a film of a pale greenish tinge, which under the microscope appeared to be made up of myriads of minute unicellular algæ. Rarely one found a few threads of *Cladophora* or other filamentous alga, but aside from these insignificant exceptions *no fixed plants*. The rich variety of forms, worms, crustaceans, mollusks and insect larvæ, dredged from the *Chara* beds of Lake St. Clair, were entirely lacking. In their place the dredge yielded in many regions a considerable number of specimens, belonging, however, only to a few genera. The *Mysis* and *Pontoporeia*, though taken from near the bottom undoubtedly obtain their food mostly from the water and are not properly bottom feeding forms. The Lamellibranchs are dependent upon the same source of food supply; but the Gastropods and a few species of insect larvæ, almost entire Chironomids, are true bottom forms. They live either on the microscopic plants or on decaying matter which has fallen from the superjacent water. Wherever fixed plants were found there was no dearth of life. The *Chara* beds found at High Island harbor were as rich in life as those of Lake St. Clair. Mr. Walker mentions in his report (Appendix V), the extraordinary number of species of mollusks obtained there from a single haul of the trawl.

It should be mentioned here that the *Chara* beds do not in themselves afford nourishment directly to any fish, or so far as I can find to any abundant animal; and hence their absence does not directly reduce the food supply. Indirectly, it affects the conditions very materially; for the beds afford shelter to myriads of small bottom forms, crustaceans, insect larvæ, and worms, which find food in the microscopic plants growing among them. Hence they are breeding beds for fish food and furnish the best of conditions for the development of bottom feeding fish. Lake Michigan does not furnish in this region a sufficient variety of bottom food for many species of bottom fish. The few forms which are found are all included in the menu of the whitefish; they seem, however, so far as our observation went, to be widely distributed and to be present each in considerable numbers.

Some of the physical characteristics of the lake, though less striking at first, are equally important. That part of the lake which lies above the ten fathom line (18.3 meters) forms but a very narrow border on the map; yet this is more than three times the greatest depth observed in Lake St. Clair. The extreme depth reached in our work was 130 meters, which is just the average for the entire lake, and not quite two-thirds of the

extreme depth. The considerable depth of most of the lakes involves very different conditions of life in the greater part of the waters from those which exist in a shallow lake. Perhaps the most important is temperature. On different days the surface temperature ([1]) of the lake varied from 16.7° to 19.4° C. (62° to 67° F.). The bottom temperature was always less than the top and in twenty to twenty-five meters was only 10° to 6.4° C. (50° to 43.5° F.) while at the deepest stations (112 and 130 m.) the thermometer registered only 4.2° C. (39.5° F.) on the bottom. In general it appears that near the surface the fall in temperature is more rapid for the same amount of descent than near the bottom; there were however, curious variations in bottom temperature at about the same depth, *e. g.* 14.4° C. at 22 meters, Station xxi, and 6.4° C. at 24 m,, Station ii, which show wide departure from the general principle of equal temperature at equal depths, owing perhaps to local conditions. Our observations are not extended enough to throw light upon special cases. The whole of the lake in this region below the limit of 25 m. from the surface has a temperature of 7.5° C. (45.5° F.), or less, which is about 11° C. (20° F.) lower than the surface temperature, while the water below 110 to 130 m. does not rise above 4° C. (39.2° F.), which is the temperature of maximum density for fresh water. Here temperature conditions are probably uniform the year through, while at the surface they are subject to the greatest fluctuations.

In the next place the amount of light decreases rapidly with the depth, and yet not so rapidly here as in ordinary lakes. Since the amount of inflow is small in proportion to the total volume of the lake, and since the shallow area where the water can become roily in time of storm is very limited, the water contains extremely little inorganic matter in suspension, and hence the northern lakes are noted for their transparency. In the Charlevoix region the water is beautifully clear and allows objects to be discerned at considerable depths. We made no tests to determine the relative transparency of the water, but its evident superiority in this respect compensates for the great depth to a large extent by permitting the passage of a much larger amount of light, and hence the development of plant life in deeper strata of the water. Again, the disturbance in time of storm does not extend very far from the surface. The ten fathom line lies far below wave action and thus the greater portion of the water is undisturbed by storms.

Furthermore, the pressure increases with the depth. At about 10 m. the pressure is twice that at the surface (one atmosphere, 15 lb. sq. in.); at 103 m., all forms are subjected to a pressure of 11 atmospheres. Yet the animals brought up from this depth seemed to suffer no inconvenience by their rapid transit from a pressure of 165 lbs. to the square inch to one of only 15 lbs. to the square inch.

Finally, the lake is free from such currents as exist in Lake St. Clair. The slow movements of the water in definite directions are not at all comparable with the stream of a river, and the limited inflow and outflow, already discussed in this report, serve to maintain the lake in a condition of stable equilibrium.

The factors just discussed are of the greatest importance in determining the character of the food supply in the lake, as well as its distribution. But it should first be noted that the question of food supply here is totally

[1]See table of plankton hauls on pages 32 to 35.

unlike similar questions in agriculture and the difference is fundamental in its character. The land animals which furnish the large part of man's food supply are herbivorous. Their supply of food is drawn from the great group of grasses, grains and forage plants, which growing before our eyes, derive nourishment from the inorganic materials in earth, air and water. There intervenes but a single step from the inorganic to the organic and the chain of biological relations is short and simple in the main. It is not only capable of immediate observation, but it has also been in all its details the subject of long continued and careful study in numerous experiment stations of the country. The preparation and the enrichment of the soil, the development of the seed, the growth of the plant, the diseases which threaten it, the enemies which attack or crowd it out, its protection and improvement have been for many years the care of trained minds on experimental fields and in well equipped laboratories. How different the case for the fish culturist! In many instances he does not even know the immediate food of the species in question. Observations on its habits and life history are all too scanty and experimentation limited and uncontrolled.

The series of biological relations are also widely different from those on the land. In fresh water there are few large plants; in the Great Lakes a still scantier amount. Among all the food fish there are none that depend on these plants for food supply; they are purely carnivorous. One of the most fundamental questions for the fish culturist is then clearly the source of food supply in the Great Lakes and the steps in the process of its transformation into fish flesh. Directly connected with this are the questions of its amount and distribution since fish culture is evidently depedent for success and development upon these factors. Unless the primitive food supply be abundant at the present time, all efforts to increase the number of fish will fail of ultimate success; unless the food of the fry is found in sufficient quantities in that locality where the fry are planted, the maximum number can never reach the adult condition; and finally the possible increase in the fish supply is limited by the amount and distribution of the food in so far as those factors are themselves beyond the control of the fish culturist.

The limited inflow of Lake Michigan renders the amount of food supplied to its waters from this source comparatively insignificant and, moreover, it is almost entirely inorganic matter which is received in this way. The limited shore areas and general lack of shore plants make the shore washings an equally unimportant source of food supply, although from it as from the preceding source would be received a certain amount of inorganic material in solution and in suspension. The occasional fields of *Chara* and other bottom algæ add only a limited amount of food, but the scanty development of this bottom flora, already commented upon, precludes the possibility of considering it more than a secondary source of food supply.

From the atmosphere is leached out by every rain much valuable inorganic matter, and the winds bring from time to time insects, both singly and in swarms, which fall a ready prey to the fish of the water. But even this is a secondary and incidental source; the biological relations of the life in the water are not seriously affected by this addition. No sufficient source of primitive organic food material can be found external to the lake; it must be sought *within the water itself.* It must also be capable of forming the inorganic material into living matter, and

since we have already seen that of the green plants which possess this power, the larger fixed forms are lacking or present in entirely insufficient quantities, it is clear that the source whatever it may be must escape notice by virtue of the minute size of its individual elements, since the abundance of the material as a whole must necessarily be presupposed.

If one draws through the water a net of finest gauze and collects its gleanings into a small glass, there will be seen a myriad of minute forms almost or quite invisible to the eye. The mass of material obtained depends not only upon the length of the haul and size of the net, but upon numerous other conditions as well. Under no probable circumstances, however, will the net fail to collect a certain amount of material which the microscope shows to be composed of living organisms of varied character. Among these are both plants and animals, the latter so insignificant that their own motion does not suffice to carry them over any considerable distance, and hence both plants and animals are dependent upon waves, currents and winds for their wide distribution. Their entire existence is passed floating freely in the water and both plants and animals possess characters of form or structure fitting them for maintaining their position. Very many are provided with long processes, enabling them to present greater surface to the water; others have oil drops reducing their specific gravity. This mass of living forms is known as the *plankton*, and it plays such an important part in the economy of the water that the relations may briefly be outlined here. One may justly call it the *primitive food supply* of the water, and as such it is of course the origin of fish food.

The smallest forms in the plankton are the one-celled plants and animals, and the first are really the actual* source of the food supply. They float, as it were, in a sort of broth, or nutritive fluid, the water containing in solution those simple inorganic substances which they are enabled by the possession of green matter (chlorophyll or some related substance) and in the presence of light to transform into living protoplasm. The well known principle that rapidity of chemical action depends upon the proportion of surface to volume, was long ago used by Leuckart to explain the extraordinary growth of these unicellular plants.† In them the proportion of surface to volume is far greater than in any larger forms; the production of protoplasm, that is growth, goes on with extreme rapidity and the simple process of reproduction by division which characterizes them, results in the production of many generations within a limited period of time. These unicellular plants are the food not only of the unicellular animals, but also of some of the higher forms, and it is on their extraordinary power of multiplication that the entire economy of the water depends in last analysis.

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*There is a large group of doubtful forms, frequently classed as animals among the flagellate protozoans; they contain chlorophyll, or some allied substance, and by virtue of this are enabled to make use of inorganic food material like the green plants. These forms, which are abundantly represented in the plankton, are classed by other authorities as plants. If the latter classification be accepted, the statement made above is exactly true; if, however, these forms are regarded as animals, there must be a minor exception recorded against the statement that the simple plants are the *only* actual source of the food supply. This is a matter both undecided and secondary at most and needs no further explanation here; it is mentioned only to avoid danger of misunderstanding the statements made in the text. In any event the primitive source of food supply is found exclusively within the unicellular forms of the plankton.

†Zacharias (95, p. 108) calls attention to the growth of these algæ as more rapid than that of the higher plants, such as rye, and finds in this evidence that "the living organic substance of which the contents of the *Melonia* threads are made must be much more easily formed anew than that of the rye." This is evidently a false conclusion; the rapidity of growth is not due to any theoretical ease of formation of the substance in question, but is clearly traceable *to the greater proportion of surface to volume*, and hence greater possibility of chemical activity, and secondly to *the total immersion of the growing body in the nutritive fluid*. In the higher plants it is also true that a considerable amount of energy must be devoted to the differentiation of organs for supplying all parts equally with nourishment. In the simpler algæ, *Melonia* in the case cited above, all parts are alike active and growing.

In the plankton are contained, however, in addition to the unicellular plants and animals already mentioned, the Rotifera and many Crustacea. Other forms seemed to be either rare or entirely wanting in the plankton taken at Charlevoix, but a more exact enumeration of the species encountered in this region may be found in the introduction and in the appendices to this report. These four elements together constitute the food supply of the lake. The unicellular plants, or Protophyta, are dependent upon inorganic nourishment; the Protozoa subsist upon these plants and both form the food of the Rotifera, while the Crustacea feed upon anything which falls in their way. The last group forms the predominating element in the plankton, constituting in almost all instances the greater portion of any haul, and they are the immediate source of food for the lake fish. The fry depend directly upon the Crustacea of the plankton and rarely also the adult draws its nourishment from the same source, as in the case of the lake herring. More frequently it is through the medium of some larger form or forms. Thus the lake trout is piscivorous and feeds upon the herring and smaller forms. Of the whitefish food, already discussed and described, each species is dependent entirely upon the plankton, living or dead and sunk to the bottom, except the univalves, which also draw a portion of their nourishment from the fixed microscopic plants of the bottom. Reighard has given (p. 24) a table showing the interdependence of the various forms of life in a fresh water lake; it includes shore and bottom forms as well as the plankton.

It was apparent soon after the work of Charlevoix began that in general the plankton did not contain as many species as in Lake St. Clair, but the total mass per volume of water proved considerably greater. This was due to the greater number of individuals of a species present. Especially striking was this in the case of the small Crustacea, for often a bottom tow made in Round Lake was so thick as to deserve the name of "crustacean soup," and yet it consisted almost entirely of a single species of Copepod. The catch recalled hauls taken in the ocean in respect to total amount of material, but was far from possessing the rich variety of forms characteristic of marine tows. Not only did none of the hauls from Round Lake show the great number of species recorded in occasional tows on Lake St. Clair, but the average haul was decidedly inferior in this respect to the average haul from the latter place. In spite of this it was regularly true that the total amount of plankton in the average haul from Round Lake was considerably greater than the total amount obtained in average hauls from Lake St. Clair. The same feature became apparent during work in Pine Lake and Lake Michigan at a later date; the plankton in these lakes contains only a limited number of species present in a large number of individuals.

QUANTITATIVE PLANKTON WORK.

Since the plankton plays such a fundamental part in the life of the water, in being the primitive food supply, some guide to the fertility of the lake will be given by ascertaining as exactly as possible its amount and its distribution, both vertically into zones and horizontally into areas if such exist. The determination of fluctuations in amount and quality with weather and seasons is of equal importance; but our observations extended over too limited a period to permit of obtaining evidence on these points. The work of the summer throws some light on the questions of amount and distribution in the Charlevoix region, important not

only in themselves, but for comparison with the data derived from similar experiments in Lake St. Clair during the previous year. Our experiments on these points were made in the course of the last two weeks of August, those of Reighard in Lake St. Clair during the second week of September. They are probably sufficiently identical in time that direct comparisons may be drawn between the figures without the danger that we are dealing with results which represent conditions of different seasons of the year. This precaution in treating the results is necessary since both Apstein and Zacharias have shown the existence in various European lakes at least of a considerable seasonable variation, both in the amount and in the quality of the plankton.

The apparatus used in these determinations was the modified vertical net described by Reighard (p. 26-29) and the process followed in the management of the net and the treatment of the material obtained was almost identical. Slight modifications introduced by the writer were successful enough to warrant mention in this place. The plankton holders made by cutting off the bottom of a short 6 dr. homeopathic vial and annealing the edges, as used in 1893, had some slight disadvantages. Apart from the waste of time and bottles in making a supply of perfect tubes, it was difficult to tie the gauze over the bottom so securely that it would not come off under some circumstances, and the mouth of the bottle was so small as to render it wearisome to change the fluids on account of the tardiness of the filtering in case the enclosed mass of plankton was at all large. In view of these two difficulties, I had Whitall, Tatum & Co. make some plankton tubes after my model. The tubes were pieces of $\frac{7}{8}$ inch glass tubing 3 inches long, with a carefully constructed flange at each end which turned outwards about one-sixteenth inch. It was found that the flare increased the filtering surface sufficiently to aid greatly in the passage of fluids and that the gauze could be tied over the end with great security and rapidity. We had occasion to preserve 11 or 12 cc. in a single tube, but in spite of the mass had no difficulty at all in filtering the water out and in getting various fluids through the tube. The flange was also of material assistance in tying the second gauze to close the tube; this was frequently done when the boat was rocking violently and in no case did we lose any of the contents of the tube. In transferring from one fluid to another a syringe bulb with a fine glass tube pipette was used to force air into the tube through one gauze end and thus render more rapid the passage of the fluid through the other gauze from the tube. I feared at first that in spite of the No. 20 silk gauze used for covering the ends of the tubes there might be some small loss of plankton on account of the pressure which could be exerted by the bulb, or at least some damage done to delicate forms; but after experimenting we could detect no loss in the washings nor damage to the most delicate forms in the plankton and hence adopted this method in all our subsequent work. These two trivial modifications mean a saving in time for each tube of plankton put up of at least twenty per cent, and much more where the amount of plankton is exceptionally large.

Between the eleventh and twenty-ninth of August eight days were spent with the fishing tug "Minnie Warren" in making stations at various points in the Charlevoix region. In all twenty-six stations were made, two in Round Lake, six in Pine Lake, and eighteen in Lake Michigan. The stations, which are indicated in order by Roman numerals on the map of the region appended to this report, were made chiefly on fishing

grounds of past or present value, and in the selection of these we had the assistance of Capt. John O'Neil of the "Minnie Warren," an old and successful fisherman of Charlevoix. In addition to the stations on fishing grounds some few were made in adjacent waters, either very shallow or very deep, in order to obtain material for the comparison of the various places. It is thought that these stations represent very fairly the different conditions which prevail in this region and afford then some idea of its character as a whole.

At each station the depth of the water and temperature of the water at bottom as well as at the surface and of the air were first taken with the sounding machine and thermometers lent by the United States Fish Commission. The condition of surface, of sky and weather were also noted and the exact position and character of the place recorded. A series of hauls with the vertical net was made at 2, 5, 10, 25, 50, 100 meters and bottom, the length of the series depending each time on the depth of the water. The contents of the net at each haul were preserved in a plankton tube of the character already described and provided with a label bearing the number of the station and haul. Further details of the process may be found in Professor Reighard's report (p. 27, 28). In this way a total of one hundred tubes of plankton were obtained.

In the table of plankton hauls (p. 32–4) it will be noticed that the depth of the water and the depth of the haul do not bear any constant relation to each other. This is due to the different methods employed in obtaining each. The depth of the water was recorded by the sounding machine, as already described, while the depth of the haul was measured on the rope of the vertical net which was marked off by meters so that the distance from the upper ring of the cone of the net to the surface of the water could be determined directly. In this way the distance through which the net was hauled could be measured without danger of error from the slight slant of the net rope or from inequalities of the bottom. This method of obtaining the depth of the haul was used for all stations after the first three (I to III[3] inclusive).

After the vertical hauls were finished, the anchor was lifted and two or more of the dredges as well as bottom and top tow nets were used to ascertain the character of the bottom and the quality of the life in the water at this place. The tows were examined by various members of the party after the return to the laboratory and the results of the examination entered on the regular blanks. This gave an approximate idea of the composition of the plankton from any station, as well as of the bottom fauna and flora. Various circumstances interfered with carrying out this plan in full at all stations. However dredgings were made in the majority of cases, including one at station xi from a depth of 112 m., but at the deepest station, 130 m., the dredge was not used.

For the determination of the quantity I used the tubes of plankton collected at the various stations and preserved as described above. The contents of each were carefully transferred to a glass cylinder or measuring tube graduated to tenths of a cubic centimeter and were allowed to settle exactly twenty-four hours. The volume was then taken and recorded. This volume is only an approximation of the amount of the plankton since the latter is very light and will settle for days if left undisturbed. It will naturally settle more quickly if shaken occasionally, and the degree of concentration it reaches depends very clearly on the character of the material in this particular plankton haul. Finally the mass

Time, 1894.			Haul.					Conditions of—						Air.			Volume of plankton in cubic centimeters.		
									Water.									Calculated, using mean velocity 0.61 m. per second.	
Month.	Day.	Hour.	Serial number.	Place.	Character.	Depth from which drawn.	Velocity in meters per second.	Bottom.	Depth in meters.	Temperature in degrees Centigrade. Bottom.	Temperature in degrees Centigrade. Top.	Surface.	Current.	Temperature in degrees Centigrade.	Wind—direction and strength.	Sky.	Taken in vertical net.	Under 1 sq. meter of surface.	Per cubic meter of water.
Aug.	11	10:30 A. M.	I	Lake Michigan	B	107.8	.60		108.22	5.1	18.9	Slightly rough			S W, 3	Hazy	9.74	176.29	1.64
"	11	12:20 P. M.	II		B	24.1	.58		24.52	6.4	18.3	"			S W, 3	"	5.08	91.95	3.83
"	11	12:50 "	II^{q}		B	24.1	.42		24.52	6.4	18.3	Nearly smooth			S W, 2	Light rain	4.20	76.02	3.2
"	11	3:45 "	III		B	50.5	.61		50.92	5.6	16.7	"			S, 1	Hazy	7.53	136.11	2.70
"	11	4:00 "	III^{2}		S	10	.77		50.92	5.6	16.7	"			S, 1	"	3.15	57.02	5.70
"	11	4:10 "	III^{3}		S	3	.75		50.92	5.6	16.7	"			S, 1	"	2.50	45.25	15.08
"	11	5:05 "	IV		B	35	.82		36.78	5.8	17.8	"			S, 1	"	9.50	171.95	4.91
"	15	10:30 A. M.	V	Pine Lake	B	22	.63		20.74	13.1	18.9	Light waves		14.8	N, 3	Cloudy	3.50	63.35	2.88
"	15	10:40 "	V^{2}		S	15	.71		20.74	13.1	18.9	"		14.8	N, 3	"	3.26	59.01	3.98
"	15	10:50 "	V^{3}		S	10	.50		20.74	13.1	18.9	"		14.8	N, 3	"	2.44	44.16	4.42
"	15	11:00 "	V^{4}		S	5	.50		20.74	13.1	18.9	"		14.8	N, 3	"	1.61	29.14	5.58
"	15	11:30 "	V^{5}		S	2	.40		20.74	13.1	18.9	"		14.8	N, 3	"	1.32	23.89	11.95
"	15	12:00 M.	VI		B	30	.56		33.01	10.4	20	Little smoother		14.4	N, 3	"	3.78	68.42	3.28
"	15	12:15 P. M.	VI^{2}		S	15	.60		33.01	10.4	20	"		14.4	N, 3	"	3.35	60.64	4.04
"	15	12:30 "	VI^{3}		S	5	.50		33.01	10.4	20	"		14.4	N, 3	"	2.35	42.54	8.51
"	15	12:45 "	VI^{4}		S	2	.50		33.01	10.4	20	"		14.4	N, 3	"	1.27	22.99	11.5
"	15	2:00 "	VII		B	30	.59	Yellow marl	33.01	10.6	18.6	Few white caps			N N W, 3	Clearing	5.30	94.12	3.14
"	15	2:30 "	VII^{2}		S	15	.63	"	33.01	10.6	18.6	" "			N N W, 3	"	3.79	68.6	4.51
"	15	2:35 "	VII^{3}		S	10	.71	"	33.01	10.6	18.6	" "			N N W, 3	"	3.18	56.65	5.67
"	15	3:45 "	VII^{4}		S	5	.56	"	33.01	10.6	18.6	" "			N N W, 3	"	3.00	54.3	10.86
"	15	3:00 "	VII^{5}		S	2	.50	"	33.01	10.6	18.6	" "			N N W, 3	"	1.68	30.41	15.20
"	15	3:45 "	VIII		B	11	.58	Marl	11.32	20	21.1	White caps		18.1	N N W, 4	Clear	3.55	64.26	5.84
"	15	4:00 "	VIII^{q}		B	11	.69	"	11.32	20	21.1	"		18.1	N N W, 4	"	3.20	57.92	5.27
"	16	9:20 A. M.	IX	Lake Michigan	S	2	.67	Sand	28.29	10	18.3	Slight swell		13.3	N W, 2	"	1.07	19.37	9.68
"	16	9:30 "	IX^{2}		S	5	.63	"	28.29	10	18.3	"		13.3	N W, 2	"	2.25	40.73	8.15
"	16	9:40 "	IX^{3}		S	10	.59	"	28.29	10	18.3	"		13.3	N W, 2	"	3.02	54.66	5.47
"	16	9:55 "	IX^{4}		S	25	.51	"	28.29	10	18.3	"		13.3	N W, 2	"	6.48	117.29	4.69
"	16	10:15 "	IX^{5}		B	26	.52	"	28.29	10	18.3	"		13.3	N W, 2	"	6.41	116.02	4.46
"	16	11:30 "	X		S	2	.57	"	55.98	5.2	18.3	Smoother		15.6	N W, 1	"	1.02	18.46	9.23
"	16	11:40 "	X^{2}		S	5	.56	"	55.98	5.2	18.3	"		15.6	N W, 1	"	1.45	26.25	5.26
"	16	11:50 "	X^{3}		S	10	.59	"	55.98	5.2	18.3	"		15.6	N W, 1	"	2.64	47.78	4.78

"	16	12:05 P. M.	X4	Lake Michigan	S	25	.54	"	55.93	5.2	18.3	"		15.6	N W,	1	"	5.85	96.84	3.87
"	16	12:20 "	X5		B	58	.59	"	55.93	5.2	18.3	"		15.6	N W,	1	"	5.90	106.79	2.01
"	16	1:50 "	XI		S	2	.57	Sand & debris	112	4.2	18.3	Rippled only		16.7	S,	1	"	1.22	22.08	11.04
"	16	1:58 "	XI2		S	5	.71	" "	112	4.2	18.3	" "		16.7	S,	1	"	1.95	35.30	7.06
"	16	2:05 "	XI3		S	10	.39	" "	112	4.2	18.3	" "		16.7	S,	1	"	3.68	66.61	6.66
"	16	2:25 "	XI4		S	25	.69	" "	112	4.2	18.3	" "		16.7	S,	1	"	6.38	115.48	4.62
"	16	2:45 "	XI5		S	50	.75	" "	112	4.2	18.3	" "		16.7	S,	1	"	8.72	157.88	3.16
"	16	3:00 "	XI6		B	112	.75	" "	112	4.2	18.3	" "		16.7	S,	1	"	9.41	170.32	1.52
"	16	4:05 "	XII		S	2	.57	Sand	5.66	18.3	18.3	" "		16.7	S,	1	"	1.48	26.79	13.39
"	16	4:15 "	XII2		B	4.3	.67	"	5.66	18.3	18.3	" "		16.7	S,	1	"	1.35	24.44	5.68
"	16	5:10 "	XIII		S	2	.57	"	32.06	7.5	18.3	" "		16.7	S W,	1	"	1.57	28.42	14.21
"	16	5:20 "	XIII2		S	5	.88	"	32.06	7.5	18.3	" "		16.7	S W,	1	"	2.30	41.63	8.33
"	16	5:30 "	XIII3		S	10	.63	"	32.06	7.5	18.3	" "		16.7	S W,	1	"	4.40	79.64	7.96
"	16	5:40 "	XIII4		S	25	.78	"	32.06	7.5	18.3	" "		16.7	S W,	1	"	9.35	169.24	6.77
"	16	5:55 "	XIII5		B	30	.75	"	32.06	7.5	18.3	" "		16.7	S W,	1	"	7.91	143.17	4.77
"	17	12:00 M.	XIV		B	8	.47	"				Rough			Terrific squall		Low clouds	3.61	65.34	8.16
"	18	9:00 A. M.	XV		S	2	.40	Mud & Chara	11.32	16.7	17.2	White caps		18.9	N E,	4	Cloudy	1.4	25.34	12.67
"	18	9:10 "	XV2		S	5	.59	" "	11.32	16.7	17.2	"		18.9	N E,	4	"	1.72	31.13	6.23
"	18	9:20 "	XV3		B	10	.68	" "	11.32	16.7	17.2	"		18.9	N E,	4	"	2.95	53.40	5.34
"	18	12:15 P. M.	XVI		S	2	.57	Sandy mud	22.63	7.2	17.5	Few white caps		16.7	N,	3	Clearing	1.50	27.15	13.58
"	18	12:25 "	XVI2		S	5	.67	"	22.63	7.2	17.5	" "		16.7	N,	3	"	2.34	42.35	8.47
"	18	12:35 "	XVI3		S	10	.77	"	22.63	7.2	17.5	" "		16.7	N,	3	"	4.47	80.91	8.09
"	18	12:45 "	XVI4		B	23.5	.57	"	22.63	7.2	17.5	" "		16.7	N,	3	"	6.98	126.34	5.38
"	18	4:30 "	XVII		S	2	.50		132.66	4.2	18.3	White caps rare		18.9	N b E,	3	Scattered cl'ds	1.29	23.35	11.67
"	18	4:35 "	XVII2		S	5	.59		132.66	4.2	18.3	" "		18.9	N b E,	3	" "	2.45	44.35	8.87
"	18	4:42 "	XVII3		S	10	.61		132.66	4.2	18.3	" "		18.9	N b E,	3	" "	4.90	88.69	8.87
"	18	4:50 "	XVII4		S	25	.57		132.66	4.2	18.3	" "		18.9	N b E,	3	" "	8.80	159.28	6.37
"	18	5:00 "	XVII5		S	50	.56		132.66	4.2	18.3	" "		18.9	N b E,	3	" "	9.90	179.19	3.58
"	18	5:20 "	XVII6		S	100	.54		132.66	4.2	18.3	" "		18.9	N b E,	3	" "	9.28	167.97	1.68
"	18	5:50 "	XVII7		B	130	.52		132.66	4.2	18.3	" "		18.9	N b E,	3	" "	8.86	160.37	1.23
"	22	3:30 "	XVIII		S	2	.57	Sand	36.78	6.4	19.4	Slight swell		21.7	W S W,	1		1.45	26.25	13.12
"	22	3:40 "	XVIII2		S	5	.63	"	36.78	6.4	19.4	"		21.7	W S W,	1		1.86	33.67	6.73
"	22	3:50 "	XVIII3		S	10	.65	"	36.78	6.4	19.4	"		21.7	W S W,	1		2.72	49.23	4.92
"	22	4:00 "	XVIII4		S	25	.58	"	36.78	6.4	19.4	"		21.7	W S W,	1		4.98	90.14	3.61
"	22	4:10 "	XVIII5		B	36	.57	"	36.78	6.4	19.4	"		21.7	W S W,	1		4.95	89.60	2.49
"	25	11:05 A. M.	XIX		S	2	.44	Sandy, shells.	35.83	7.5	18.9	Few white caps	*	21.9	N,	3		1.42	25.70	12.85
"	25	11:15 "	XIX2		S	5	.56	" "	35.83	7.5	18.9	" "	*	21.9	N,	3		1.93	34.93	6.99
"	25	11:28 "	XIX3		S	10	.54	" "	35.83	7.5	18.9	" "	*	21.9	N,	3		3.25	58.83	5.88
"	25	11:35 "	XIX4		S	25	.64	" "	35.83	7.5	18.9	" "	*	21.9	N,	3		6.55	118.56	4.74
"	25	11:45 "	XIX5		B	36	.58	" "	35.83	7.5	18.9	" "	*	21.9	N,	3		11.90	215.39	*5.98
"	25	1:10 P. M.	XX		S	2	.44	Smooth sand	39.6	7.5	19.4	Rippled			S W,	1		1.02	18.46	9.23
"	25	1:15 "	XX2		S	5	.59	" "	39.6	7.5	19.4	"			S W,	1		1.75	31.68	6.34
"	25	1:25 "	XX3		S	10	.65	" "	39.6	7.5	19.4	"			S W,	1		2.74	49.59	4.96
"	25	1:35 "	XX4		S	25	.64	" "	39.6	7.5	19.4	"			S W,	1		4.58	82.9	3.32
"	25	1:45 "	XX5		B	41	.59	" "	39.6	7.5	19.4	"			S W,	1		6.08	110.05	2.68

* For discussion of this haul see pages 38 and 45. The figures are given in the table without correction.

Time, 1894.			Haul.					Conditions of—									Volume of plankton in cubic centimeters.		
									Water.					Air.				Calculated, using mean velocity 0.61 m. per second.	
Month.	Day.	Hour.	Serial number.	Place.	Character.	Depth from which drawn.	Velocity in meters per second.	Bottom.	Depth in meters.	Temperature in degrees Centigrade. Bottom.	Temperature in degrees Centigrade. Top.	Surface.	Current.	Temperature in degrees Centigrade.	Wind—direction and strength.	Sky.	Taken in vertical net.	Under 1 sq. meter of surface.	Per cubic meter of water.
Aug.	25	2:00 P. M.	XXI	Lake Michigan	S	2	.44	....	22.63	14.4	19.4	Rippled	--	24.2	N, 2......	....	1.28	23.17	11.58
"	25	2:08 "	XXI^{2}		S	5	.59	....	22.63	14.4	19.4	"	--	24.2	N, 2......	....	1.94	35.11	7.02
"	25	2:15 "	XXI^{3}		S	10	.63	....	22.63	14.4	19.4	"	--	24.2	N, 2......	....	2.78	50.82	5.03
"	25	2:22 "	XXI^{4}		B	22	.79	....	22.63	14.4	19.4	"	--	24.2	N, 2......	....	4.90	88.69	4.03
"	25	3:20 "	XXII		S	2	.57	Mud	43.88	7.2	19.4	Rough	--	20	N, 2......	....	.98	17.74	3.87
"	25	3:25 "	XXII^{2}		S	5	.56	"	43.88	7.2	19.4	"	--	20	N, 2......	....	1.38	24.98	5.00
"	25	3:33 "	XXII^{3}		S	10	.65	"	43.88	7.2	19.4	"	--	20	N, 2......	....	2.73	49.41	4.94
"	25	3:40 "	XXII^{4}		S	25	.60	"	43.88	7.2	19.4	"	--	20	N, 2......	....	4.19	75.84	3.03
"	25	3:50 "	XXII^{5}		B	42	.71	"	43.38	7.2	19.4	"	--	20	N, 2......	....	5.60	101.36	2.41
"	29	3:00 "	XXIII	Round Lake	S	2	.57	Marl	18.86	18.1	18.3	Light swell	--	16.1	N, 5......	Cloudy	1.62	29.33	14.66
"	29	3:05 "	XXIII^{2}		S	5	.67	"	18.86	18.1	18.3	"	--	16.1	N, 5......	"	1.85	33.49	6.7
"	29	3:10 "	XXIII^{3}		S	10	.54	"	18.86	18.1	18.3	"	--	16.1	N, 5......	"	2.51	45.43	4.54
"	29	3:15 "	XXIII^{4}		B	17.5	.67	"	18.86	18.1	18.3	"	--	16.1	N, 5......	"	3.83	69.32	3.96
"	29	3:30 "	XXIV		S	2	.67	"	6.6	18.3	18.3	Rippled	--	16.1	N, 5......	"	1.60	28.96	14.48
"	29	3:35 "	XXIV^{2}		B	4	.57	"	6.6	18.3	18.3	"	--	16.1	N, 5......	"	1.52	27.51	6.88
"	29	4:15 "	XXV	Pine Lake.	S	2	.67	Blue marl	15.09	13.1	16.1	Rough	--	16.7	N, 5......	Clearing	1 20	21.72	10.86
"	29	4:20 "	XXV^{2}		S	5	.83	" "	15.09	13.1	16.1	"	--	16.7	N, 5......	"	1.88	34.08	6.81
"	29	4:25 "	XXV^{3}		S	10	.87	" "	15.09	13.1	16.1	"	--	16.7	N, 5......	"	3.10	56.11	5.61
"	29	4:30 "	XXV^{4}		B	15	.83	" "	15.09	13.1	16.1	"	--	16.7	N, 5......	"	2.63	47.60	3.17
"	29	4:45 "	XXVI		S	2	.67	Marl	21.69	11.1	16.1	Little rough....	--	18.3	N, 4......	"	1.41	25.52	12.76
"	29	4:50 "	XXVI^{2}		S	5	.71	"	21.69	11.1	16.1	"	--	18.3	N, 4......	"	1.49	26.97	5.39
"	29	5:00 "	XXVI^{3}		S	10	.77	"	21.69	11.1	16.1	"	--	18.3	N, 4......	"	2.6	47.06	4.71
"	29	5:10 "	XXVI^{4}		B	21	.62	"	21.69	11.1	16.1	"	--	18.3	N, 4......	"	2.71	49.05	2.34

obtained depends to some extent upon the diameter of the measuring tube in which the settling is done, as I ascertained in the course of some experiments on this matter. These experiments are discussed in full in another paper, and it is sufficient to note here that the volumes entered in the table were measured in the same tubes and as exactly as possible under the same conditions as those recorded by Reighard for Lake St. Clair. The results, then, are directly comparable with those he gives (p. 29, 30), and are also an approximate measure of the amount of plankton in these waters. The volumes obtained are entered in the table of plankton hauls given here (pp. 32–4.)

These volumes are relative to the size of the net; and as was first shown by Hensen (87) and as is explained also by Reighard (p. 28), for general use it is necessary to apply a total correction in order to find the amount of plankton under one square meter of surface. In this way are eliminated the special features due to the size of the individual net employed and the filtering power of the material used in its construction. In the first place, the net opening has not an area of one square meter and in the second place the resistance of the stuff forces some water aside, so that the net does not filter the entire column of water through which it passes. The area of the net opening is 1,237.86 sq. cm., so the correction for the area is 8.08. Hensen has given a table of corrections for varying velocities also, and these were used by Reighard, though the uncertainty of the method by which they were calculated was discussed in an appendix (p. 57) to his report. In some cases Reighard was forced to adopt a correction for an average velocity since that for the observed velocity was such as to make the result an absurdity. Similar cases occurred in my own calculations as for instance at station IV, where the amount of plankton per cubic meter of water was more for the entire depth than any station furnished in the surface statum, and as will be shown later, this stratum contains always more than any other of similar thickness. I, therefore, calculated the amounts on the basis both of the observed velocity and of the average velocity, and plotted the results in a manner to be explained later. It was at once evident on the examination of the plot that the lines were practically coincident except in a few cases, and in half of these the results based upon observed velocity were evidently false. I therefore decided to use a correction of 18.10 based upon an average velocity of 0.61 m. per second and a net opening of $\frac{1}{8.08}$ sq. m. And the amounts under each square meter of surface as given in the table are obtained by multiplying the volume of plankton taken by this average correction of 18.10. The results in the corresponding column of Reighard's table were obtained by using the actual correction according to Hensen's method save in the few instances noted. My adoption of an average correction was influenced not only by the facts above but also by some other considerations. In the first place a physicist, who at my request made a very careful examination of Hensen's method of approximations, gave it as his opinion that the physical principles involved would not hold good for velocities at either extreme, if indeed they were correct for mean velocities. In the next place, it is difficult to observe the *exact* time of a haul and the error in observation, which is of course increased by movements of the boat or by irregularities of the surface of the water, is proportionally very much greater for the shallower strata. Finally in comparing results of Reighard, and myself, it will be possible to see whether the the deductions made hold good under both circumstances, that is are really

general principles, or whether they are modified in any way by the method of calculation employed.

The volume per cubic meter of water as given in the table is obtained by dividing the volume under one square meter of surface by the depth of haul. Other details of the table are self explanatory. The hauls at stations I to IV inclusive were made on the first day and were somewhat experimental; they differ from the others in method of handling and preserving, and have not the same series of strata in depth; they are hence discarded in the study of strata. The hauls at XIV* were interrupted by a terrific squall and hence this is also omitted in the same connection.

A brief consideration of the question will show that the errors in the method employed are all in one direction and tend constantly to reduce the real amount, to make the final result less than the quantity actually present in the water. Although carefully guarded against, the loss of minute quantities by accident or in the course of the numerous manipulations undoubtedly does take place. Pauses however slight, or unequal velocities in movement during the raising of the net, failure of the gauze to filter as rapidly as usual owing to clogging or to some other cause, reduce the amount of water filtered by the net and hence also the amount of plankton obtained below that actually present in the column. Finally some forms, good swimmers, will escape the net as it is hauled up; this error is evidently less with our net, having an opening of 1,238 sq. cm. in area than with the nets used in European lakes by Zacharias and Apstein in which the area of the opening did not exceed 64 to 100 sq. cm.

This method does not, then, give absolute exactitude, nor can I see why that would be more desirable if possible. The variations in the amount of plankton present are greater far than the errors of the method, as already illustrated, and the approximation obtained by this method is sufficiently near for practical purposes. Certainly it is true that, since all errors tend only to reduce the actual amount, *the volume of plankton present is not less than the figures given in the table.* A single exception must be made in those cases when foreign matter is accidentally included in the net but these are easily detected by microscopic examination of the mass.

From Lake Michigan in the Charlevoix region eighteen bottom hauls show the following results in total amount of plankton obtained:

Number of Station	I.	II.	III.	IV.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XX.	XXI.	XXII.	Av.
Volume of Plankton in cubic centimeters per cubic meter of water	1.64	3.82 3.20	2.70	4.91	4.46	2.01	1.52	5.68	4.77	8.16	5.34	5.38	1.23	2.49	2.68	4.08	2.41	3.69

* Stations will be denoted hereafter by a Roman numeral only.

In Round and Pine lakes, which have immediate and free connection with Lake Michigan at Charlevoix, the amounts obtained in nine bottom hauls were as follows:

Number of Station	V.	VI.	VII.	VIII.	XXIII.	XXIV.	XXV.	XXVI.	Av.
Volume of Plankton in cubic centimeters per cubic meter of water	2.88	2.28	3.14	5.84 5.27	3.96	6.88	3.17	2.34	3.97

Twenty-seven bottom hauls were made in Lake St. Clair in 1893, two at each station except the first, with the following results (Reighard 94, p. 31):

Number of Station	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XIII.	XIV.	XV.	XVI.	Av.
Volume of Plankton in cubic centimeters per cubic meter of water	4.97 ----	1.44 2.68	2.76 3.89	2.01 2.01	2.74 3.62	2.29 3.08	3.69 3.69	2.70 3.01	2.54 2.39	4.15 4.15	4.79 3.97	3.60 3.31	1.80 2.42	1.90 2.83	3.03 ----

The total average for all Lake Michigan stations is 3.69 cc. of plankton per cubic meter of water. In Lake St. Clair the total average was 3.03 cc. per cubic meter of water. But the stations in Lake St. Clair varied in depth from 1.5 to 5.6 meters, while Lake Michigan hauls extended from 4 to 130 m., so that the comparison should be made with corresponding hauls of the latter only, and these have an average of 6.39 cc. or more than double the amount of the St. Clair hauls. The tabulation of results (Pl. I and III) afford a graphic presentation of these relations. *Lake St. Clair contains only half as much plankton per cubic meter of water as is taken from water of equal depth in Lake Michigan at Charlevoix.*

Reighard records (p. 37) the average of four bottom hauls made in Lake Erie in 1893, as 8.98 cc. per cubic meter of water. If compared with the hauls of corresponding depth in Lake Michigan they are evidently richer, and that by forty per cent. Reighard notes, however, the peculiar location and richness of the two stations at which the four hauls were made and mentions a third station with a different location and a much smaller volume of plankton. Including this haul also, the average of all the Lake Erie stations is 7.41 cc. of plankton per cubic meter of water, which is nearly one-sixth more than the average of stations of equal depth on Lake Michigan at Charlevoix. The number of observations is too small to permit of a positive statement, but it seems probable that there is somewhat more plankton per cubic meter of water in the western end of Lake Erie than in water of equal depth in Lake Michigan near Charlevoix.

In comparison with the volumes for European lakes, given by Apstein (94), Lake Michigan in the Charlevoix region is decidedly "plankton poor." Thus, in September, Great Plöner See, which is a typical "plankton poor" lake, contains, for a depth of 40 meters, 5 cc. of plankton per cubic meter of water. In Lake Michigan, two hauls of almost the same depth, XX and XXII, averaged only 2.55 cc. of plankton per cubic meter of water, or about one-half as much. And yet this small amount which is present constitutes *in toto* a tremendous mass. The estimated volume of Lake Michigan is about 7,500,000 millions of cubic meters, and if the average of the lake contains an amount of plankton per cubic meter of water equal only to the

lowest amount for any bottom haul of the Charlevoix region (1.23 cc. at XVII^7), the total mass of plankton in the entire lake would equal *more than nine and one-third millions of cubic meters.* This deepest haul, XVII^7, was made at about the average depth of the lake and hence may well be taken as a representative haul for the lake, especially since, as the chart shows (Pl. I), this haul does not depart appreciably from the normal line of relative volumes—to be discussed later.

It is valuable to consider for a moment what actual amount of food is contained in this volume of plankton. For this purpose two masses of plankton, XIII^4 and XIX^4 were selected as average hauls, and XIX^5 as an instance of a haul which was evidently much polluted by foreign matter. The plankton was shaken up in a limited quantity of alcohol and a certain portion of the mixture removed, weighed, air-dried and weighed again. The weight of the same sample was also taken when dried to a constant weight at 100° C. and after calcining the ash was weighed. The ash was then digested in concentrated hydrochloric acid, washed, dried and weighed to obtain the approximate amount of sand present.* The plankton which remained after the removal of the small portion treated in the manner just described, was measured by the volumetric method and from this the exact portion removed was calculated from the original volume of the plankton. These results are expressed in the following table:

Number of haul.	Depth in meters of—		Volume in cc.		Percentage of original volume used.	Weight in milligrams.			
	Haul.	Water.	Original volume of haul.	Volume measured after removal of part.		Air dried sample.	Sample dried to constant weight at 100° C.	Ash in sample.	Silicious matter in sample.
XIII^4	25	32	9.35	4.88	47.8	53	50	7.6	2.3
XIX^4	25	36	6.55	1.00	84.7	61	57	8.	2.1
XIX^5	36	35	11.90	9.61	19.2	207	206	160.	112.

From these data may be obtained by simple calculation the following table in which figures are given to the nearest whole number:

Number of haul.	Percentage in air dried sample of—				Weight in milligrams for entire haul of—			Weight in grams of plankton under 1 sq. m. of surface.	
	Organic.	Entire ash.	Ash, not sand.	Sand.	Air dried.	Ash.	Sand.	Air dried.	Ash.
XIII^4	85.7	14.3	10.7	3.6	111	16	4.8	2.0091	0.2896
XIX^4	86.8	13.2	9.8	3.4	72	9	2.5	1.3082	0.1629
XIX^5	22.6	77.4	23.2	54.2	1077	833	583	19.5118	15.0773

A microscopical examination of XIII^4 and XIX^4 shows that they are very nearly pure plankton. We may then from the average of these two estimate that such plankton contains about 3.5 per cent of silicious mate-

* These processes were very kindly carried out for me in the chemical laboratory of the University of Nebraska, by Mr. E. E. Nicholson, to whom my sincere thanks are due.

rial, 10 per cent of other earthy substances, largely calcareous, and 86 per cent of organic substance. The first element is entirely useless as food and the second somewhat so, but the third consists almost wholly of nutritive matter. From this somewhat rough calculation it may be seen that the plankton contains almost wholly matter useful as food and that the percentage of useless matter is very small.

Comparing these figures with those from XIX[5] it appears that there is in the latter haul an excess of 50 per cent in sand and 64 per cent in total inorganic matter. This represents foreign matter included in that haul and yet not all since there was also organic matter stirred up from the bottom in the haul and 75 per cent is a low estimate of the total foreign substance; this would make the actual volume about 7.5 cc. A more detailed description of the process and of its value in plankton studies may be found in another paper (Ward, 96[a]).

Hensen (87, p. 34) has made some determinations of the percentage of the various elements in oceanic plankton, with the following results for fresh plankton hauls, which were drained nearly dry and then subjected to quantitative analysis. These hauls were composed largely of diatoms and contained also a certain unknown amount of sea water:

Organic matter	42.1	25.5	39.6
Soluble salts	7.3	43.8	17.3
Insoluble salts	50.6	30.7	43.1

The large percentage of soluble salts is undoubtedly due, in part at least, to the salt of the sea water, but even after the elimination of that factor, it will be seen that the lake plankton is very much richer in organic material, that is, in actual food matter. Some analyses of single species given by Hensen approach more nearly to the results obtained for the lake plankton. Thus *Mysis*, analyzed after drying, contained 89.6% of organic and 10.4% of inorganic matter; for *Salpa* the percentages were 85.4 and 14.6. and for other species similar results were obtained. From this it appears that the lake plankton is much more nearly pure food material than the marine plankton, having not far from the same proportion of organic matter that is contained in the more favorable forms from the ocean.

The total amount of plankton in the lake may also be estimated from the average volume of the two normal hauls XIII[4] and XIX[4]. Both hauls are from a depth of 25 m. and as will be shown this distance includes the great bulk of the plankton. The small amount below this limit will more than balance the deficiency in such limited areas as are less than 25 meters in depth. Under 1 sq. m. of surface at a depth of 25 m. these hauls show 1.5 to 2 g. of plankton, which amounts to 15 to 20 kg. to the hectare. The total area of Lake Michigan is about six million hectares or six hundred square myriameters. A weight of plankton equal to 15 to 20 kg. to the hectare becomes 150,000 to 200,000 kg., or 150 to 200 metric tons to the square myriameter, or for the entire lake a mass of six hundred times that quantity, making the total weight of plankton in Lake Michigan not less than 90,000 to 120,000 metric tons.* Unless there is a much larger amount of plankton in the Charlevoix region than in other parts of the lake, a condition not at all likely, this estimate is conservative and falls below the true amount, since in it was discarded all the plankton lying below the 25 meter line. It is true that below this limit there may not be a large quan-

*A metric ton is almost exactly equal to the English "long ton."

tity to the cúbic meter, yet the enormous area of the lake and the considerable depth below that limit would make even a small factor important on the whole. The table on page 50 shows that nearly half of this is contained in the surface stratum of two meters in thickness; or, expressed in terms of the actual amount, the surface two meters of Lake Michigan contains from 40,000 to 60,000 metric tons of plankton.

This calculation may be verified by a second computation, made on a different basis. As shown above, Lake Michigan is estimated to contain about 9,300,000 cubic meters of plankton. From the table given on page 38, it appears that 1 cc. of plankton weighs about .011 to .012 g., or 1 cubic meter would weigh 11 to 12 kg. The total mass of plankton in the lake, 9,300,000 cu. m., would on this basis weigh from 102,300,000 to 118,600,000 kg. or 102,300 to 118,600 metric tons. The close agreement in the results reached by this and the preceding method is evidence of the correctness of the approximation.

From these data it is easy to estimate the amount of plankton found under each acre of surface. Thus, 15 to 20 kg. to the hectare would equal 12 to 16 lb. per acre of surface. In comparing this with the production of the land it is necessary to consider the very high proportion of organic matter present here. Hensen (87, p. 96) has made a similar calculation for the ocean on the basis of the sum total of increment in the plankton from haul to haul; thus in a dozen periods having a total length of 228 days, the sum of all the increments in the plankton was 4,162 ccm.; an average of 18 ccm. per day, which in the course of the year would equal 6,570 ccm., and on the basis of analysis would contain 15-17 g. of organic material. The destruction of food matter by the Copepoda he had previously calculated at 133 g. yearly; hence the total yearly production must be at least 150 g. per square meter of surface. The estimated production of a similar area in grain would be 180 g. of dry organic matter, so that the water is little if any inferior and the consideration of other factors may easily show its productivity to be greater than that of the land.

More recently Zacharias (95, p. 107) has essayed a similar estimate on the basis of a single element, the increase in the amount of *Melosira* which reached within 29 days the sum of 1,500 kg. per hectare, or 1,200 lb. per acre.

From comparison of these figures with those of the fertility of the land, as measured by various crops, these authors are inclined to believe the productivity of the water equal to that of the land, or even slightly greater than it. There are, however, certain sources of error, especially in the latter comparison, which materially influence the result. In the first place the comparison is made by both authors with land in a high state of cultivation, whereas, the water is as yet untouched by like processes of stimulation. But more than this, the land which is taken as the basis for comparison, is protected from inroads and the entire product of its fertility stored up for future use. In the case of the water, the plankton is subject to daily and hourly diminution, one form devouring another until the material is finally carried beyond the reach of all calculations. The periodic increase in the volume of the plankton takes place in spite of the constant drain on its mass; and even were there no increase at any time, it is clearly evident that there must be active growth to keep the volume constant. To measure this growth, or to arrive at an approximate idea of the fertility of the water is, I think, beyond the limit of present possibilities. More data with reference to the continuous consumption of the plankton than

those afforded by a single group must be obtained before we can estimate its ratio of growth. But least of all can the productivity of the water be measured by the abnormal increase of a single factor in the plankton. One thing is certain the productivity of the water is great enough to keep the food supply intact against all inroads made thus far. When the first European settlers reached this region they found the waters of the lakes teeming with fish. At least an equal number could thrive now in these waters.

DISTRIBUTION OF THE PLANKTON.

The distribution of the mass of food material is of the greatest moment for the fish culturist and the existence of variations in the quantity deserves careful investigation. There are in fact several problems here. The plankton may be equally or unequally distributed at various times of the year; independent of such seasonal variations there may be also variations in the amount found in different parts of the lake, the horizontal or areal distribution, and finally at any given time of year and point in the lake the plankton present may be unequally distributed in various levels of the water The last question, that of vertical distribution, may be subject to modification during the course of twenty-four hours as a result of periodic migration or of passive change in level on the part of the various components of the plankton. Each of these questions will be discussed in the light of the investigations made at Charlevoix.

It is evident that only long continued observations in any region can throw light on the first question, that of seasonal distribution. Thus far the only information on the yearly variations of the plankton in any locality comes from a paper by Apstein (92) in which is given the yearly curve of plankton volumes for Gross Plöner See in Holstein. This shows a rapid increase through August and September to the maximum which falls near the beginning of October and an equally rapid decrease from that time through November. The minimum occurs in February but the decrease to it and increase from it are gradual. It would be venturesome to hold that the seasonal variation in Lake Michigan was the same, yet a similar increase in amount with the rising temperature of the water and decrease with lowering of the same is altogether probable. If this be so our observations were made during the time in which the volume of plankton was approaching its maximum.

If long extended observations are necessary for the determination of seasonal variations, the reverse is true in the investigation of horizontal or areal distribution. In order to avoid the progressive yearly variations in the mass of plankton those observations which are to be used for comparison in determining horizontal and vertical distribution must be made within a limited time. It is evident then that the series of hauls made in Lake St. Clair and in Lake Michigan are peculiarly fitted for the discussion of these questions since each series fell within a limit of ten days; and since both were made at almost exactly the same season of the year they may safely be compared with each other also. The results possess great strength as scientific evidence since they are deduced not from single isolated experiments, in which error or chance may play a promiment part, but are based upon systematic observations numerous enough to eliminate chance and to show whatever errors may inhere in the methods employed. This cannot be too strongly emphasized in the light of a growing tendency

to discover principles and to corroborate the work of other investigators on the evidence afforded by a single experiment!

The first element which may be considered in its effect on areal distribution is depth. The hauls made in the Charlevoix region are well fitted to afford evidence on this question since they cover very wide conditions in respect to depth. Omitting those few hauls which have already been set aside as experimental or failing to agree in some important particular with the others, the remainder may be grouped in four classes; the first three include those made in Lake Michigan and the fourth those from Round and Pine lakes. Class A includes Lake Michigan hauls made in water from 4 to 12 meters deep; B those from a depth of 20 to 42 meters and C comprises those hauls from water whose depth varies between 50 and 130 meters while in D are grouped all those made in Round and Pine lakes where the water was 4 to 30 meters deep. The hauls under D are not sufficiently numerous for subdivision although they evidently correspond to those of both A and B in Lake Michigan.

		Total No.
A.	Shallow hauls in Lake Michigan include XII, (XIV),* XV	6
B.	Medium " " " " " (II, IV,) IX, XIII, XVI, XVIII, XIX, XX, XXI, XXII	41
C.	Deep hauls in Lake Michigan include (I, III,) X, XI, XVII	22
D.	Hauls in smaller lakes include V, VI, VII, (VIII), XXIII, XXIV, XXV, XXVI	30
	Total number of hauls made	99

If for the various bottom hauls the total amounts of plankton obtained are brought together and then averaged for the separate groups, we have the following:

A. No. of Station	XII.	XIV.	XV.	Average.
Total volume in cc. of plankton obtained	1.35	3.61	2.95	2.64

B. No. of Station	II.	IV.	IX.	XIII.	XVI.	XVIII.	XIX.	XX.	XXI.	XXII.	Av.
Total volume in cc. of plankton obtained	5.08 4.20	9.50	6.41	7.91	6.98	4.95	? 11.90 **	6.08	4.90	5.60	6.16

C. Number of Station	I.	III.	X.	XI.	XVII.	Av.
Total volume in cc. of plankton obtained	9.74	7.52	5.90	9.41	8.86	8.29

Considering then the Lake Michigan stations alone it is evident that at least to the limit of our experiments, *the total amount of plankton increases with the depth of the water.* The average amount for all stations in Lake Michigan is obtained from the total average of the three tables, and reaches 6.16 cc., being curiously the same as the average amount for

* Those in parenthesis are not available for the study of the various strata.
** Omitted in the average for reasons given on page 45.

stations of medium depth. For comparison the table of total amounts for class D is given here.

D. Number of Station	V.	VI.	VII.	VIII.	XXIII.	XXIV.	XXV.	XXVI.	Av.
Total volume in cc. of plankton obtained	3.50	3.78	5.20	3.55 3.20	3.83	1.52	2.63	2.71	3.32

It must be remembered that Group D includes stations of all depths in Pine and Round lakes and ought to be compared with the sum of A and B rather than with any one or all of the Lake Michigan groups. From this it would appear that the total amount of plankton is somewhat smaller in Pine and Round lakes than it is in adjacent waters of Lake Michigan.

From Reighard's table of plankton hauls (pp. 29, 30) the average amount taken in all bottom hauls in Lake St. Clair is found to be only 0.63 cc. and for the four bottom hauls taken in Lake Erie 2.98 cc. It is difficult to compare these amounts correctly with each other or with the results given above, since the depth is different at each station; and there is furthermore no basis for comparison with the results obtained by other investigators with a vertical net of a different size. If, however, instead of taking the total amount of plankton obtained in each bottom haul, we compare the amount per cubic meter of water as found for each bottom haul by calculation and entered in the last column of the table, close comparisons can then be made between the different hauls. This is done in the following tables:

A. Number of Station	XII.	XIV.	XV.	Av.
Amount of plankton in cc. per cu. m. of water	5.68	8.16	5.34	6.39

B. Number of Station	II.	IV.	IX.	XIII.	XVI.	XVIII.	XIX	XX.	XXI	XXII.	Av.
Amount of plankton in cc. per cu. m. of water	3.82 3.20	4.91	4.46	4.77	5.38	2.49	5.98 *	2.68	4.08	2.41	3.82

C. Number of Station	I.	III.	X.	XI.	XVII.	Av.
Amount of plankton in cc. per cu. m. of water	1.64	2.70	2.01	1.52	1.23	1.82

D. Number of Station	V.	VI.	VII.	VIII.	XXIII.	XXIV.	XXV.	XXVI.	Av.
Amount of plankton in cc. per cu. m. of water	2.88	2.28	3.14	5.84 5.27	3.96	6.88	3.17	2.34	3.98

From these tables it appears that the volume of plankton per cubic meter of water is greatest at the shallower stations, and least at the deepest stations while the medium hauls retain a mean position with reference to

* Not averaged; see pages 38 and 45.

the others. Before comparing the stations in class D it should be noted that there may be taken two sets of hauls corresponding to groups A and B; the first consists of VIII and XXIV, hauls having a depth of 4 to 11 meters, and agrees almost exactly with the limits of class A (4 to 12 m.) while the hauls V, VI, VII, XXVI from depths of 21 to 30m. correspond closely to the shallower half of class B. Hauls XXIII and XXV come between the two and are set aside for the moment. The average volume of plankton per cubic meter of water is for the first set 6 cc., a trifle less than the average of hauls in class A, and for the second set it is only 2.66 cc. which is much less than the average for class B. It should be noted also that the hauls correspond only to those in the shallower half of class B and this should have the greater amount of plankton per cubic meter of water if the principle just stated, namely, the decrease in amount of plankton per cubic meter of water with increase in depth of the water, holds true of the stations in general as it has already been shown to obtain in the artificial groups A, B, and C. And in fact the average for those stations in class B having a depth between 22 and 30 meters is 4.18 cc. which is nearly sixty per cent greater than the average amount from the stations of equal depth in Pine Lake. This seems to show first, that the average amount of plankton per cubic meter of water is somewhat less in Round Lake and in the shallow part of Pine Lake than in corresponding depths of Lake Michigan; and secondly that in the deeper portion of Pine Lake the amount of plankton per cubic meter of water is very much less than at stations of equal depth in Lake Michigan.

Comparisons simply by figures such as the preceding are somewhat unsatisfactory in that they can not ordinarily be kept in mind or arranged in such a way that their interrelation becomes perfectly clear. So, for instance, in the sets of tables just given (pp. 42 and 43) it was shown that the total volume of plankton increases with the depth but the volume per cubic meter of water decreases under the same circumstances. This was clear as between the three artificial series of hauls, A, B, and C, of which averages were given. But the question is naturally suggested as to whether it also holds true of the terms of the series and to what extent it is regular or periodical. In other words, are the increase in total volume of plankton and the decrease in volume per cubic meter of water comparatively constant, or does one find sudden changes at certain points. It was in the course of studies upon these questions that I hit upon a method of representation which shows these relations most clearly and unmistakably.

If common "cross-section paper" of suitable size and ruling be employed and if the vertical lines be taken to represent stations and the horizontal lines distances or amounts, a line may be drawn connecting the various points denoting the depth of each haul, and this may be called the line of depths. Similarly, by connecting points, indicating the total volume of plankton obtained in a bottom haul at each station, a line of total volumes is obtained and in a like manner a line of volumes per cubic meter of water. The position of the lines will then indicate clearly the relations between the factors of depth, total volume and volume per cubic meter of water. This has been done for all the bottom hauls in Lake Michigan (Pl. I), which are arranged in order of depth so that the line of depth (D) turns continuously in one direction from the shallowest haul (XII) at one side of the plate to the deepest (XVII) at the other. The course of this line of total volumes (T) is not entirely in the single direction, but there are numerous retrogressive variations, the most marked of which is that

made at the vertical XIX. This was a noticeable point in the first rough draft of the plate, and I set at once to work in order to find, if possible, the cause of such an irregularity, for, when there could be found no mistake in the calculation, the idea of a swarm came up at once since such an abrupt increase and decrease in comparison with the antecedant and the subsequent haul of nearly equal depth must have been due to the localized massing of the plankton, in full or in part, or to something foreign. It proved to be the latter; for in my field notes was entered against this haul (XIX^6) "full of sand (current?), probably poor for measuring," and at the time of measuring this tube of plankton I noted opposite the amount, "too much sand, throw out." By approximation from the hauls of (XVIII) and (XX), which agree closely in time, place, and general conditions, as well as in amounts at other depths, I judged the amount of true plankton to be about 7.5 cc. instead of 11.90 cc. as measured and entered in the table.* This haul is more fully discussed elsewhere in connection with the vertical distribution of the plankton. I have hence drawn a dotted line to indicate more nearly the true relation of the plankton for XIX. As far as the other variations are concerned, they are not sufficient to change or even mask the relation of this line of total volumes to the depth, and hence they may be passed here. It may be that they are due to a cause similar to that in the case just explained, but less in amount, or to errors in the instruments or methods employed, or finally to actual small variations from the normal in the amount of plankton in a certain place.

So far as the general tendency of this line (T) is concerned it agreed with the line of depth but shows also an individual variation. During the first part of its course it indicates a uniform increase in the total volume more rapid than the increase in depth; after a depth of about thirty meters has been attained, however, its direction is variable and uncertain until the sudden change in depth between X and XI where it marks an increase less decided than that in the depth. The slight decrease at XVII would be an equally slight increase were the amount for the haul of 50 meters at this station substituted for that from the bottom; that is the amount of plankton is approximately equal at the two stations XI and XVII. The relations between the depth and the total amount of plankton present may be summarized as follows: Up to about thirty meters of depth the amount of plankton found in the lake increases more rapidly than the depth, but beyond fifty meters decidedly less rapidly. Further experiments are necessary to determine whether there is comparative uniformity in amount or a slight increase for depths beyond one hundred meters.

The third line on this plate (R) joins points on the verticals of the various stations, indicating by their distances from the upper margin the amount of plankton in cubic centimeters per cubic meter of water, as shown in the last column of the table (pp. 32–34). In contrast to the line of total volumes last considered it may be called the line of relative volumes. It will at once be clear that it follows the opposite direction from the line of total volumes and shows a decided decrease from the shallower stations to the deeper. It is also most irregular in the first half of its course and there also departs most from the dotted line of averages which is almost coincident with it near the end. This is undoubtedly due in large part to the greater influence on the amount per cubic meter which is exerted by errors in the capture of the material or in measurement later, since the divisor, the depth of the water, is a smaller number for the shallower sta-

* Almost exactly the same result was reached by a more complicated method; see p. 38.

tions. An error of measurement for instance causes a greater departure from the normal when distributed over only eight meters of depth than when divided among fifty to one hundred meters.

In the next place it is evident that local conditions influence most strongly the shallower stations. Some are sheltered by projecting shores or are on wide areas of shallow water where the temperature is higher than in a more exposed situation. Currents or winds may also accumulate plankton at such points or may reduce the average amount somewhat. All of these agencies are less likely to act unequally in the freer open waters. At some of the shore stations, which show the greatest variations from the average a current could be noticed but it was difficult on account of the wind and the roughness of the water to determine without special instruments which were not at our command, its direction and strength. The dotted line which is a part of the line of relative volumes is thought to indicate closely the average amount of plankton per cubic meter of water and the irregularities of the solid line (R) show then the variations from that average. It will be noticed that no variation is equal to one-third of the relative volume and that most of them are very much less than that. The extreme deflection at XIX is of course due to the same cause as that in the line of total volumes and the dotted line from XVIII to XX indicates a correction on the same basis as that already discussed for the line of total volumes.

It may be noticed that some stations are omitted from the chart. They are those mentioned on page 42 at which, owing to various causes, a series of hauls was not made and which on that account cannot be used in the following tables and in the discussion of the vertical distribution of the plankton. They are therefore omitted here also in order that the various charts may be capable of being exactly compared. If included, the lines on the chart would not have been materially altered.

The following conclusions may then be drawn from these studies as to the amount of plankton in Lake Michigan in the Charlevoix region.

I. The total volume increases with the depth, but more rapidly for depths up to about thirty meters than beyond that point.

II. The volume per cubic meter of water decreases as the water grows deeper. This decrease is irregular for the shallower stations, but comparatively constant in deeper water.

III. No variation is large enough to warrant the assumption of the existence of alternate densely crowded and barren areas in the water, i. e. of masses or "swarms" of the plankton as a whole.

On plate I^B are plotted the same lines for the stations, in Pine and Round lakes. A glance will suffice to show that the same conclusions may be drawn here also, the total volume of plankton obtained in the bottom hauls increases comparatively regularly with the depth and with approximately equal rapidity for all depths reached. However, all stations made, and in fact the extreme depth of the lake, fall within the thirty meter limit which was seen to be about the termination of the rapid increase in the total volume of plankton in Lake Michigan. The amount per cubic meter of water as shown by the line of relative volumes (R) decreases very rapidly in the shallower regions but remains comparatively constant for hauls of twenty meters or more. The numbers of hauls in Round and Pine lakes is rather small to use as the basis of general conclusions on the distribution of the plankton in these waters, but so far

as they go they show exactly similar conditions to those prevailing in Lake Michigan.

In the comparison, which should be made only with the part of I^A lying to the left of the vertical XIII, however, it is noticeable that both the line of total volumes and that of relative volumes fall above the corresponding lines for stations of equal depth in Lake Michigan. With the exception of those at the shallowest station *all hauls in the smaller lakes show both absolutely and relatively less plankton than was taken in hauls of the same depth from Lake Michigan.*

I have taken from the table given in Reighard's report corresponding data on the depth, the total and relative volumes of the plankton for Lake St. Clair and have plotted them in a similar manner (Pl. III). The line of total volumes (T) increases slightly but with striking uniformity from the shallowest to the deepest station and throughout its course closely parallels the line of depth (D). The line of relative volumes (R) is somewhat irregular, especially at the shallower stations. A general tendency in its course is not pronounced but it certainly does not show a decrease with increase in depth. In other words the total amount of plankton per cubic meter of water, taken in bottom hauls in Lake St. Clair, seems to be nearly if not quite independent of the depth of the water.

The explanation of the apparent contradiction between this and the distribution of the plankton in the northern lakes as described above, is to be found in the widely different conditions which obtain in the two places. Only one station in Lake Michigan came within the limits of the deepest of the sixteen bottom hauls in Lake St. Clair. The meagre depth of the latter region is accompanied by minimal diferences in the temperature of the water at the top and bottom, 1° C. being the greatest difference recorded. In the next place the considerable inflow and outflow cause rapid exchange and continual mixing of the water at all levels and make Lake St. Clair merely an expansion in the course of a river. It is as such subject to widely different influences which yield results naturally unlike those that obtain in the deep and stable waters of the northern lakes.

In one respect the chart of hauls from Lake St. Clair affords even more decided evidence than those of Lake Michigan and Pine Lake. There is no difference considerable enough to warrant the assumption of the existence of swarms of the plankton as a whole.

The question of temperature was carefully studied but I was unable to detect any relation between the volume or variations of the plankton and the temperatures recorded at the various stations. I was also unsuccessful in discovering other factors which affect the areal distribution of the mass and am inclined to think that in the St. Clair and Charlevoix regions at least depth is the only prominent factor influencing the horizontal distribution of the entire mass of the plankton.

The entire discussion thus far has been based upon a study of the various bottom hauls, but there was made also at each station a series of partial hauls. The comparison of these partial hauls with each other and with the bottom hauls show some particulars with reference to the vertical distribution of the plankton as a whole which deserve consideration here. In the course of correspondence with Professor Reighard during the past year, he sent me a synopsis of the possibilities in the case which seems of much value in its bearings on the question under consideration as to warrant its reproduction here.

"The following conditions are possible with regard to the distribution of plankton in a body of water.

I. The plankton may be uniformly distributed through the whole volume of water. This condition is thought not to exist in nature.

II. The plankton is unequally distributed, and the water may be divided into artificial strata in which

A. The volume of plankton per cubic meter of water is unequal for different strata of equal thickness but

1. *Equal for different parts of the same stratum.*—This is the condition to be expected from the nature of the environment which in so far as it is not influenced by currents, may be said to vary with the depth but to remain constant throughout any thin horizontal stratum. It is the condition defended by Apstein and would yield in all parts of a lake equal volumes for equal depths, whether hauls extended to the bottom or not.
2. *Unequal for different parts of the same stratum;* in this case there are two possible groups of cases.
   a. The inequalities of the strata may be so arranged as to compensate each other in such manner that in vertical columns of water of equal dimensions extending from the bottom to the surface there will always exist equal volumes of plankton in different parts of the lake. This would result from II. A. 1. in case migrations of large numbers of individuals occurred only vertically. This condition would yield equal volumes for equal *bottom* hauls but unequal volumes for some other equal hauls.
   b. Or arranged without reference to each other so that vertical columns of water of equal dimensions and extending from surface to bottom will usually contain unequal volumes of plankton in different parts of the lake. This would result from I. or II. A. 1, by migration of masses of individuals horizontally or obliquely. Such migrating masses may produce local accumulations of any conceivable form or size, such as spheres, sheets extending horizontally or vertically, etc. They are thus capable of producing a wide range of variation in the volume of the plankton from bottom and other hauls.

The migrating masses may consist of all the species existing in the plankton and in the proportions in which they exist there—in which case the resulting local accumulations may be called *plankton swarms*; or they may consist of one or several species and might be called *species swarms*. Species swarms occurring in such way as to compensate one another would remain undetected by the volumetric method."

The work of the first day with the vertical net was experimental, and does not show any uniformity in the number or depth of the various hauls at each station, as given in the table, page 32. They cannot be used for this reason in the comparative study of the strata. In all hauls thereafter we distinguished a number of artificial strata as follows:

1. A surface stratum from 2 m. to the surface.
2. An intermediate stratum from 5 m. to 2 m.
3. An " " " 10 " " 5 "
4. An " " " 25 " " 10 "
5. A deep " " 50 " " 25 "
6. A " " " 100 " " 50 "
7. A " " below 100 "

Twenty hauls each were made for the first two groups, while only two fall in the last group, and in all calculations, except the first table where all hauls are recorded, these are included in the stratum above as from the bottom to 50 m. The amount of plankton under one square meter of surface obtained in the various hauls from Lake Michigan is shown in the following table:

Number of Station	IX.	X.	XI.	XIII.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.
2 m. to surface	19.37	18.46	22.08	28.42	25.84	27.15	23.85	26.25	25.70	18.46	28.17	17.74
5 m. to surface	40.73	26.25	35.30	41.63	31.13	42.35	44.35	33.67	34.93	31.68	35.11	24.98
10 m. to surface	54.66	47.78	66.61	79.64	58.40	80.91	88.69	49.23	58.83	49.59	50.32	49.41
25 m. to surface	117.29	96.84	115.48	169.24	------	126.34	159.28	90.14	118.56	82.90	88.69	75.84
50 m. to surface	116.02	106.79	157.83	148.17	------	------	179.19	89.60	? ? ?	110.05	------	101.36
Bottom to surface	------	------	170.32	------	------	------	160.37	------	------	------	------	------
Depth of bottom haul	26	53	112	30	10	23.5	130	36	36	41	22	42

The amount for the deepest stratum in each column represents the haul from the bottom, this usually does not coincide exactly with the deep limit of the stratum, but its extent can easily be told by the depth of the station, which is given in the lowest line of figures.

Corresponding figures for the stations in Round and Pine lakes are given in the next table.

Number of Station	V.	VI.	VII.	XXIII.	XXV.	XXVI.
2 m. to surface	23.59	22.99	30.41	29.32	21.72	25.52
5 m. to surface	29.14	42.54	54.30	33.49	34.08	26.97
10 m. to surface	44.16	------	56.65	45.43	56.11	47.06
15 m. to surface	59.01	60.64	68.60	------	47.60	------
Bottom to surface	63.35	68.42	94.12	69.32	------	49.05
Depth of bottom haul	22	30	30	17.5	15	21.

If now the amount given for the surface stratum of any station be subtracted from the amount taken in the haul from 5 m. to the surface, the remainder may be held to represent the amount in the stratum from 5 m. to 2 m. In the same way we may obtain the amount for the stratum from 10 m. to 5 m. and for that from 25 m. to 10 m., as also for the strata from the bottom to 25 m. The results for the Lake Michigan hauls are given in the next table; they are, however, calculated to the nearest single decimal only.

Number of Station	IX.	X.	XI.	XIII.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.
2 m. to surface	19.4	18.5	22.1	28.4	25.3	27.2	23.4	26.3	25.7	18.5	23.2	17.7
5 m. to 2 m.	21.4	7.8	13.2	13.2	5.8	15.2	21.0	7.4	9.2	13.2	11.9	7.2
10 m. to 2 m.	13.9	21.5	31.3	38.0	22.3	38.6	44.3	15.6	23.9	17.9	15.2	24.4
25 m. to 10 m.	62.6	49.1	48.9	89.6	......	45.4	70.6	40.9	59.7	33.3	38.4	26.4
50 m. to 25 m.	-1.8	10.0	42.4	-26.1	......	......	19.9	-0.5	???	27.2	......	25.5
Bottom to 50 m.	......	......	12.5	......	......	......	-18.3	......	......	......	......	......
Depth of bottom haul	26	58	112	30	10	23.5	130	36	36	41	22	42

These artificial strata are, however, of very different thickness and in order to compare the amounts contained in them with each other it is necessary to reduce them to a common term, namely, the amount of plankton per cubic meter of water. This is done by dividing the total amount in any stratum for any station by the thickness of the stratum, and the results are given in the next table.

Number of Station.	IX.	X.	XI.	XIII.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	Average. Volume	Average. Per cent.
Amount per cu. m. in stratum 0-2 m.	9.7	9.2	11.0	14.2	12.7	13.6	11.7	13.1	12.9	9.2	11.6	8.9	11.5	*47.5*
In stratum 2-5 m.	7.1	2.6	4.4	4.4	1.9	5.1	7.0	2.5	3.1	4.4	4.0	2.4	4.1	*16.9*
" " 5-10 m.	2.8	4.3	6.3	7.6	4.5	7.7	8.9	3.1	4.8	3.6	3.0	4.9	5.1	*21.1*
" " 10-25 m.	4.2	3.3	3.3	6.0	......	3.4	4.7	2.7	4.0	2.2	3.2	1.8	3.5	*14.4*
" " 25-50 m.	-1.3	0.4	1.7	-5.2	......	......	0.8	-0.0	???	1.7	......	1.5	0	......
" " 50 m. to bottom	....	....	0.2	......	......	......	-0.2	......	......	......	......	......	0	......
Depth of bottom haul	26	53	112	30	10	23.5	130	36	36	41	22	42	....	......

It is at once apparent that the surface stratum contains a much greater amount, than any other stratum, on the average more than twice as much. The intermediate strata are not far from equal, and the deeper strata are almost without plankton. Reighard found in Lake St. Clair that the amount in the surface stratum which in his experiments was taken to be only of one and one-half meters in thickness, was greater than the total amount below, but this was evidently due to the shallowness of the water. In Lake Michigan it was nearly true of the shallowest station in the table (XV), but at all others the total amount below the two meter level was much greater than that above that line. Proportionally, however, the surface stratum is always much richer than any of those below it. In this connection it should be pointed out that the upper level, be it 1.5 or 2 m., is most susceptible to error. The time is estimated with great difficulty

and hence the velocity is hardly correctly obtained. When an average velocity is made the basis for the correction of all hauls, as in the table used here, this difficulty is of little importance. More weighty errors are due to wave motion and to the difficulty of limiting exactly the depth desired since the error is a much greater part of the whole than the same amount would be for deeper stratal hauls. One would expect, however, errors in both directions, and since the *minimum* amount of plankton in the surface stratum is more than the *maximum* amount in any other deeper stratum it is evident that the difference in the true volumes of the strata is greater than double the possible error. Furthermore, the fluctuations in the amount of plankton contained in the surface stratum are not due to this alone since they are no greater than the variations for other strata where these errors play a lesser and evidently somewhat insignificant part.

The amounts in the various strata in Pine and Round lakes are obtained in like manner, by subtraction, and are as follows:

Number of station	V.	VI.	VII.	XXIII.	XXIV.	XXV.	XXVI.
2 m. to surface	23.9	23.0	30.4	29.3	29.0	21.7	25.5
5 m. to 2 m.	5.3	19.6	23.9	4.3	-1.5	12.3	1.5
10 m. to 5 m.	15.0	18.1	2.4	11.9	....	22.1	20.1
15 m. to 10 m.	14.9		12.0	23.9	.....	-8.5	2.0
Bottom to 15 m.	4.3	7.8	25.5		......	....	
Depth in meters	22	30	30	17.5	4.	15	21

If, now, the amounts per cubic meter of water in each stratum be found as before, the table becomes:

Number of Station	V.	VI.	VII.	XXIII.	XXIV.	XXV.	XXVI.	Av. volume.	
								In cc.	Per cent.
Amount per cu. m. in stratum 0—2 m.	11.9	11.5	15.2	14.7	14.5	10.9	12.8	13.1	*64.8*
In stratum 2 to 5 m.	1.8	6.5	8.0	1.4	-0.7	4.1	0.5	3.1	*15.3*
" " 5 to 10 m.	3.0	1.8*	0.5	2.4	....	4.4	4.0	2.7	*13.3*
" " 10 to 15 m.	3.0	1.8*	2.4	3.2	......	-1.7	0.2	1.3	*6.5*
" " 15 m. to bottom	0.6	0.5	1.7		......	......			
Depth of haul in meters	22	30	30	17.5	4	15	21	....	....

Here again it is evident that the surface stratum contains much more than any equal amount of water below it, in every case at least twice as much, and on the average four times as much as any other stratum. Both the average and the extremes show that the surface stratum in Round and Pine lakes contains noticeably more plankton than the surface stratum in Lake Michigan. The deeper strata, however, appear to be decidedly poorer than those in Lake Michigan.

The results given in these last two tables are much more easily examined when represented graphically, as in Plate II. As before, the vertical lines represent stations and the horizonial lines volumes or depths as indicated at the margin. The order of the various stations is the same as that of Plate I, and the dotted line of depth (D) is repeated here for convenience.

* These were not taken as two separate hauls but together as one. See table page 32.

The points representing volumes of plankton per cubic meter of water at various depths are connected to form lines, *S* of the surface stratum, 2–5, 5–10, etc., of the other strata. The interrogation points on XIX indicate, in the case of the one at 8.8 cc. the total actually obtained for the stratum 25–50 m., sand and all included (see p. 45), and in the case of the upper mark, a possible true value for the plankton less sand and other extraneous matter. At VIII the mark indicates that the observation for this depth is lacking. The line *B* on Plate II^A represents the stratum 15 m. to bottom, which does not correspond exactly to any in Lake Michigan. Otherwise the strata are represented by similar lines on the two portions of the chart.

The results from Lake Michigan (II^A) may well be considered first separately from those of Round and Pine lakes (II^B). The line (*S*) of volumes in the surface stratum (0–2 m.) pursues a somewhat irregular course from one side of the chart to the other. The irregularities in it are independent of the depth and, as comparison with Plate I^A shows, also of the total volume and of the relative volume of plankton. I have plotted on charts not given in this report the fluctuations for these hauls in temperature of this stratum and in time of day without finding any general agreement between them and the variations in the amount of plankton in the surface stratum. These latter may be due in part at least to errors in the apparatus, in the methods of obtaining, or measuring the plankton, or they may depend upon the combined effect of several causes. At present, however, the irregularities must be left unexplained.

The lines representing the three intermediate strata occupy a mean position on the chart. They are subject to very considerable variations which bring first one and again another uppermost, but which are never sufficient to confuse any one of them with the lines of the surface stratum or of the deeper layers. On the plate the line of volumes per cubic meter of water in any stratum is marked by the limits of the stratum, *eg.* 2–5 m., but in the discussion each may well be designated by the numeral of the deeper limit of the stratum, thus the 5 m. line would indicate the line of plankton volumes per cubic meter of water in the stratum 2–5., or bottom if shallower than 5 m.

The 5 m. line shows no relation to the line of depth, nor to that of the surface stratum, and only an uncertain parallel to the line of total volumes (Plate I^A), as if it in general influenced the direction of the latter. The 10 m. line appears to have no fixed relation to the line of depth, to that of total volumes, or to the 5 m. line. There is, however, a striking agreement in direction with the line of the surface stratum; what may be the significance of this I am unable to say. At one station (IX) only is the 10 m. line on the chart, far above the 5 m. line, at two (XXI, XX) it is a little higher and at all others decidedly lower, thus indicating more positively than the average of the table (p. 50) that the 5–10 m. stratum contains more plankton per cubic meter of water than the 2–5 m. stratum. At IX the 2–5 m. stratum seems to have gained plankton at the expense of both the surface stratum and that of immediately below itself (5–10 m.) The possible significance of this will be discussed later.

The 25 m. lines shows no particular relation to the lines of depth, of total volumes, or of the surface stratum. It is more nearly parallel to the 5 m. line than to the 10 m. line, and on the chart lies below the latter in one case only (IX) while it is above the 5 m. line in seven cases and below in four. The amount of plankton per cubic meter of water is, then, in the 10–25 m. stratum clearly less than in the 5–10 m. layer and considering the

number of cases more nearly equal to the amount per cubic meter of water in the 2–5 m. stratum than the average of the table (p. 50) would indicate. The amount of plankton in the intermediate strata is variably more or less, and relatively nearly the same for the various stata, but always much less than in the surface stratum and equally clearly more than in the deeper strata. It is less than zero in one instance only, for the 2–5 m. stratum at XII.,* where the depth of the haul is only 4.3 m.

The 50 m. line shows no apparent relation to any of the others; it indicates a negative amount of plankton in at least three cases IX, XIII, XVIII, and never more than a very small positive amount. The same is true in still greater degree of the 100 m., or bottom line, which lies once just above and once just below the zero line. The amount of plankton per cubic meter of water in the deeper strata is thus clearly shown to be exceedingly small.

In Round and Pine lakes (Plate II^{B}) the relations are substantially the same. The line of the surface stratum stands for a little larger amount and shows less extreme fluctuations. The intermediate strata contain much less plankton and are much more variable in quantity. The high average of the 2–5 m. stratum in the table (p. 51,) is seen from the chart to be due evidently to the enormous bend in the line at VI and VII; at all of the other stations the 10 m. line shows a greater amount of plankton than the 5 m. line. There are in the shallower water of these lakes no strata corresponding to the deep ones of Lake Michigan, and the 10–15 m. stratum corresponds only to the upper third of the corresponding (10–25 m.) stratum in the large lake. In comparing these results with those in Lake Michigan it should be remembered that the meagre depth 30 m., of the deepest station entitles us to consider only the right hand portion of the other chart (II^{B}) up to and including XIII. The number of stations in Lake Michigan of equal depth is about the same as the total number in Round and Pine lakes.

In Lake St. Clair Reighard made hauls from 1.5, 3.0, 4.5 metres and bottom; if the second and third be added to the strata become 1.5, 4.5 and bottom which corresponds nearly with our strata of 2 m., 5 m., and bottom in the shallowest hauls. Combined in this way the hauls from Lake St. Clair yielded the following results where the volume of plankton under 1 square meter of surface is given in cubic centimetres.

Number of Station	II.	III.	V.	VI.	VIII.	IX.	XV.	XVI.
In stratum 1.5 m. to 0	10.3	15.8	11.1	8.0	9.4	7.6	7.5	7.1
" " 4.5 m. or 5 m. to 1.5 m.	0	-2.3	2.5	4.8	3.3	3.0	6.4	2.5
" " bottom to 4.5 m.	-------	4.9	3.1	-------	-------	-------	-3.0	-------
Depth of bottom haul in meters	5	5.5	5.3	4.8	4.4	4.3	5.2	4.6

By dividing in each case by the number representing the thickness of

* By the use of the method of subtraction the amount of plankton in any stratum may become apparently less than zero where the total amount in the stratum is less than the fluctuations in the measured amount of the plankton in the superjacent water whether those fluctuations are due to errors in apparatus employed, in calculation or in measurement, to actual variations in the amount of plankton present, or finally to a combination of these causes. It will then evidently be most likely to occur where the depth of the bottom stratum is only small and where it is poorest in plankton. Instances of negative plankton quantities due to the limited thickness of the bottom stratum are probably XII, IX, XIII, to poverty of the bottom stratum XVIII, XVII, though both causes undoubtedly affect some of the cases to a certain degree.

the stratum, the amount per cubic meter in each stratum will be obtained. It is given in the next table:

Number of Station	II.	III.	V.	VI.	VIII.	IX.	XV.	XVI.	Av.
In stratum 1.5 m. to 0	6.9	10.5	7.4	5.3	6.8	5.1	5.0	4.7	6.4
" " 4.5 or 5 m. to 1.5	0	-0.8	0.8	1.5	1.1	1.1	2.1	0.8	0.8
" " bottom to 4.5 m.	....	4.9	3.9	....	....	....	-4.3	....	1.5

Compared with the averages from Lake Michigan and Round and Pine lakes as given in the tables, pp. 50 and 51, it is at once evident that the surface stratum in Lake St. Clair, contains only about half as much plankton as that in the other lakes; there is still less in the second stratum. The bottom layer was present in so few cases that one can not draw any inferences from the exceedingly variable amounts given in the table above. They show, however, on the average about half as much as is found in the third stratum in Round and Pine lakes.

When these results are plotted (Plate III) it is seen that the amount per cubic meter in the surface stratum undergoes a gradual increase with increasing depth. This, which was not true of the waters of the Charlevoix region, may be a characteristic of the extremely shallow water. One can think that the true plankton forms do not reach the conditions for most favorable development until further removed from the influence of the bottom than the meagre 2 to 3 meters of the shallow hauls in Lake St. Clair. This supposition is apparently strengthened by the facts shown in the average of the table on the preceding page and is still more clearly evident on the plates.* The amount of plankton in the surface stratum is only about half as much in Lake St. Clair as in the northern waters, but in the deepest water of the former lake the amount is about the same as the smallest quantity recorded in the Charlevoix region. I am inclined to believe then that the amount of plankton in the surface stratum increases with the depth for very shallow waters until a certain maximum is approximated, and then is independent of the depth of the water. This is, however, hardly more than a working hypothesis at present and deserves further careful investigation.

The stratum 4.5–1.5 m. shows a certain decrease with increasing depth of water, the reverse of conditions in the surface stratum while the few observations on a deeper stratum, bottom to 4.5 m., agree in general tendency to increase with the surface stratum. The amount in the middle stratum is evidently far below that in the northern lakes and the variations are more intense since the amount of plankton present becomes nearly zero more than once. In this respect, the lines on Plate II^{B}, for Round and Pine lakes agree more nearly with Lake St. Clair than do those of Lake Michigan.

The peculiar tendency of proximate strata to show variations in opposite directions is evident in Lake St. Clair as well as in Lake Michigan, in connection with which the matter is discussed. Here it is only necessary to say I regard this peculiarity as evidence of vertical migration of part or all of this plankton under circumstances not yet known.

One feature deserves further discussion. No doubt it has already been noticed that the comparison between stratal hauls in the lakes is open to

* Plates I, II, III, are all drawn on exactly the same scale.

criticism since in Lake St. Clair the limits are not the same as in the northern lakes studied. It is true that as yet no definite information is at hand as to the exact position in a stratum which the mass of the plankton holds and if in Lake St. Clair a considerable part of the plankton from the stratum 1.5–4.5 m. were to have been found in *the upper half meter* of that stratum the total for the surface two meters would more nearly or quite equal that in the same limits in Lake Michigan. In the work on Lake St. Clain the stratal hauls employed were 1.5–0, 3.0–0, 4.5–0, and bottom –0. Now it is a curious fact, and perhaps not without bearing in the present discussion, that the method of subtraction gives for the four strata an average amount of plankton per cubic meter of water of 6.4, 1.6, –0.1, and 1.5 cc. That is of the two layers, each one and one-half meters thick, which constitute the stratum 4.5–1.5 m., most nearly corresponding to that of 5–2 m. used in the Charlevoix work, *the deeper one contains on the average a little less than nothing.* This shows distinctly that the bulk of the plankton in Lake St. Clair, between the limits of 4.5 and 1.5 meters is accumulated in the upper half of the stratum; how much more narrowly it is limited cannot be told. Hence it may still be true that the upper two meters contains an amount equal to the surface stratum in Lake Michigan. If this is so, however, it is all the more true that the deeper water contains a minimal amount of plankton, far below that which is found in the waters of the Charlevoix region.

One interesting general relation deserves special notice here though it has already been hinted at in the preceding. There seems to me to be evidence of opposite variation in adjacent strata and of parallel variation in strata once removed from each other, i. e., decrease in the surface stratum seems to be accompanied in a majority of instances by increase in the 2–5m. stratum and decrease in the 5–10m. stratum; and at least one of these two fluctuations appears to be generally characteristic of changes in any line. I am inclined to think this is evidence of vertical migration, under circumstances not yet apparent, of some elements of the plankton which, being normally near the artificial line of separation of two strata such as we used, would cause contrary variations in the two strata by passing from the one into the other. Reighard (93, p. 35) gives similar evidence of vertical migration by the contrary variation of proximate strata in Lake St. Clair. The solution of such questions depends, however, upon the location and movement of the species which constitute the plankton.

In the work of Apstein on the Lakes of Holstein, the artificial strata employed were 0 to 2 meters, 2 to 10 meters and 10 meters to bottom. To compare the results of this work on Lake Michigan with his the amounts for the various strata must be added so as to give layers corresponding here to those he employed. If the table on p. 50 be treated so as to combine the strata in this way, the following table is made, showing in cc. the volume of plankton under 1 sq. m. of surface for each stratum at each station:

Number of Station	IX.	X.	XI.	XIII.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.
2 m.—surface	19.4	18.5	22.1	28.4	25.3	27.2	28.4	26.3	25.7	18.5	28.2	17.7
10 m.—2 m.	35.3	29.3	44.5	51.2	28.1	53.8	65.3	23.0	33.1	31.1	27.1	31.6
Bottom—10 m.	61.3	59.1	103.8	68.5	......	45.4	71.7	40.4	* 16.5	60.5	38.4	51.9

* Estimated.

Or reduced as before to common terms for comparison.

Number of Stations	IX.	X.	XI.	XIII.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	Av.
Amount of plankton per cu. m. of water in surface stratum	9.7	9.2	11.0	14.2	12.7	13.6	11.7	13.1	12.9	9.2	11.6	8.9	11.5
In 2—10 m. stratum	4.4	3.7	5.6	6.4	3.5	6.7	8.2	2.6	4.2	3.9	3.4	3.9	4.7
In 10 m.—bot'm stratum	4.4	1.4	1.0	3.2	......	3.4	0.6	1.6	* 1.5	2.0	3.2	1.6	2.2

If now the amount of plankton in the bottom stratum of each station in the above table be taken as a unit for that station and the upper strata expressed in terms of it, the results will show the relative distribution of plankton. This has been done in the next table.

Number of Station	IX.	X.	XI.	XIII.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.
Surface stratum	2.2	6.6	11.0	4.4	4.0	19.5	8.2	8.6	4.6	3.6	5.6
2 to 10 m. stratum	1	2.6	5 6	2.0	2.0	13.7	1.6	2.8	2.0	1.1	2.4
10 m. to bottom	1	1	1	1	1	1	1	1	1	1	1

Apstein has made similar comparisons for one of the largest of German lakes, Dobersdorfersee near Kiel, and gives the following table of relations for that body of water, which has however only the limited depth of 20 m. at most.

Date	VII. 5	VII. 19	VIII. 2	VIII. 30	IX. 20	X. 4	X. 11	XI. 15	III. 27	IV. 13	V. 11
Number of haul	26	27	28	30	32	33	34	37	41	43	46
Stratum 0 to 2 m	1.7	2	4.2	3.9	7.9	1.7	2.9	4.2	6.8	2.5	3.8
" 2 to 10 m	1	1	0.9	3.9	2.9	0.2	0.6	1	2	0.5	0.9
" 10 to 20 m	1	1	1	1	1	1	1	1	1	1	1

The date of our work was August, so that comparisons should be made properly only with the first three hauls of this table; they are, however, all much alike, and show greater uniformity than those from Lake Michigan given in the preceding table. This is no doubt due to the difference in depth, for the two deep stations in Lake Michigan, XI with 112 m., and XVII with 130 m., are just the ones in which the surface stratum is extremely large in proportion to the deep stratum. The other stations, especially the shallower ones, IX, XIII, XVI, XXI, show a proportionate distribution of plankton approximately like that found by Apstein. This is the more unexpected and interesting when the amount of plankton in the two lakes is considered, for Dobersdorfer See is rich in plankton, whereas Lake Michigan belongs to those lakes denominated plankton poor. Hauls of equal depth show the latter very clearly.

* Estimated.

	Lake Michigan.				Dobersdorfer See.			
Number of haul	XII.	XIV.	XV.	XXI.	25	27	26	27
Depth of haul in meters	4.3	8	10	22	5	7	18	19
Total amount of plankton in cc. under 1 sq. m. of surface	27 24	 65	 53	 89	379 530	 227	909 909	530 720

In hauls from equal depths there is about ten times as much plankton under 1 sq. m. of surface in Dobersdorfer See as is found in Lake Michigan. Yet not only is the amount in the surface stratum of both greater than the amount in any other equal portion of the water, but it is also true that the two lakes show a greater similarity in percentage of vertical distribution of the plankton. This may be formulated as follows:

*Partial vertical hauls from equal depths yield equal volumes in the same lake, and equal percentages in different lakes.**

If we consider the relations shown by the lines on Plate II^{A}, a more natural combination of the strata used in the work on Lake Michigan than that used by Apstein for those of Dobersdorfer See, would be, (1) the surface stratum alone, richest in plankton; (2) the three intermediate strata, nearly equal to one another in amount of plankton present in each; (3) the deep strata uniformly poor in plankton.

For comparison the results are brought together into another table which gives the amount of plankton in cubic centimeters under one square meter of surface for the three sets of strata:

Number of station	IX.	X.	XI.	XIII.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.
2 m. to surface	19.4	18.5	22.1	28.4	27.2	23.4	26.3	25.7	18.5	23.2	17.7
25 m. to 2 m.	97.9	78.4	93.4	140.8	99.2	135.9	68.9	92.8	64.4	65.5	58.0
Bottom to 25 m.	-1.3	10.0	54.9	-26.1	......	1.1	-0.5	?	27.2	....	25.5

By dividing the total amount in each stratum by the thickness of the

* Since writing the above I have seen a paper by Walter (95). He speaks of quantitative plankton measurements as "an invaluable aid in the investigations" of the shallow breeding ponds on which he worked, and prefers measurements to weighing for their convenience and accuracy. The paper is almost exclusively devoted to methods, but one general principle of plankton distribution, cited without the data on which it is founded, deserves mention here. He says: "In a cubic meter of water taken from a shallow area the amount of plankton is greater than in a cubic meter from a deeper place," and further "I do not know to what extent this is true of deeper bodies of water." As will be seen, this is a somewhat general statement of the relations between the depth and the amount of plankton which are discussed more precisely in the preceding pages. Independent and concurrent observations on the value of plankton measurements and on the variation in amount with depth in bodies of water affording such sharply contrasted conditions as the shallow carp ponds and the Great Lakes are certainly powerful arguments for the accuracy of plankton studies and also in support of the general principles elucidated in this particular case.

The importance of depth as a factor in determining the amount of plankton is further evident from the observations of Zacharias (95). He states (p. 119) that there is an evident dependence of the amount of plankton on the depth of the water, but what may be the interrelation is not stated more exactly in that place. An examination of his records of hauls shows that it must be in general the same as that we found in Lake Michigan and elsewhere. It should be noted that only series of hauls made within a comparatively limited time can be compared for this purpose, since the well-known seasonal variations in the plankton certainly affect markedly the volumes of hauls made at considerable time intervals from each other.

stratum for each station, the table shows the amount of plankton in cubic centimeters per cubic meter of water at each station:

Number of Station	IX.	X.	XI.	XIII.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	Av.
In stratum 0 to 2 m.	9.7	9.2	11.0	14.2	13.6	11.7	13.1	12.9	9.2	11.6	8.9	11.5
" " 2 to 25 m.	4.3	3.4	4.1	6.1	4.3	5.9	2.8	4.0	2.8	2.8	2.5	3.9
" " 25 m. to bottom	-1.3	0.4	0.6	-5.2	......	0	0.	?	1.7	......	1.5	?
Thickness in meters of deepest stratum	1	28	87	5	......	105	11	11	16	......	17	....

If for each station of this table the amount of plankton in the intermediate stratum be taken as a unit, and the amounts in the surface and deep strata be expressed in terms of this unit, the result is as follows:

Number of Station	IX.	X.	XI.	XIII.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	Av.
Surface stratum	2.3	2.7	2.7	2.3	3.2	2.0	4.7	3.2	3.3	4.1	3.6	3.1
Intermediate stratum	1	1	1	1	1	1	1	1	1	1	1	1
Deep stratum	-0.3	0.1	0.1	-0.8	......	0	0	......	0.6	......	0.6	0.0

This table demonstrates once more and clearly that (1) the surface two meters contain much more plankton per cubic meter of water than any stratum below it, and (2) the deep stratum is practically devoid of plankton in comparison with the upper portions of the water.

This relative superiority of the surface stratum in plankton contents was first demonstrated in European lakes by Apstein. As already noted these lakes are of limited area and depth, and moderate inflow and outflow. Reighard found the same plankton distribution in Lake St. Clair which is greater in area, less in depth and extremely unstable in volume owing to the enormous inflow and outflow. The observations recorded here serve to show similar conditions in the Charlevoix region of Lake Michigan, which, even in the limited region examined, is much larger in area, many times greater in depth and extremely stable in volume owing to the small inflow and outflow. At the same time we found like conditions in Round and Pine lakes, one very small and changeable, the other large and comparatively stable. In the light of these observations on widely separate and extremely dissimilar bodies of fresh water, it may fairly be assumed to be a general truth that the surface stratum contains more plankton than any other equal portion of the water. In Lake Michigan, as also in Round and Pine lakes it was equally true that the amount of plankton in the surface stratum is independent of the depth.

The question naturally suggests itself as to the distribution of the plankton within this stratum. The surface towings in Round and Pine lakes and Lake Michigan were ordinarily made at about 8 a. m., and the blanks on which were recorded the daily catches show unmistakably that the plankton at the immediate surface contained algæ and rotifers, but only very rarely crustaceans and then but few of them. The amount of these tows was never taken carefully and measured but they showed themselves at a glance to be meagre in comparison with towings from deeper levels. In order to test the matter more carefully I had a net of peculiar

pattern constructed. From its general appearance it received at the hands of the party the name of "torpedo" net. A cylinder of wire gauze was reenforced by bands of brass at both ends and by three longitudinal brass wires of one-eighth inch in diameter, soldered to the gauze and strengthened by external hooks of wire. The front end was provided with a tight fitting, solid funnel which had external eyelets so that it could be firmly fastened to the ends of the longitudinal rods on the outside of the cylinder. Three of these funnels were used, having openings of 0.5, 0.75, and one inch in diameter. The other end of the cylinder was also closed by a funnel but of gauze with an oil can top at the end. The inside of the cylinder and of the lower funnel was lined by a net of fine India linen. From the cord which towed the net a lead weight was suspended about a foot in front of the mouth of the front funnel. Thus equipped it could be drawn behind our fishing tug at full speed and yet remain well below the surface of the water. The amount of water which could enter was regulated by the opening of the funnel and was small enough to allow of its filtering through the large lateral area of the net so as to leave the plankton in good condition. The material washed back along the sides of the net and collected in the rear funnel from which it was taken when the net was hauled in. We dragged this net for several days during our trips on Lake Michigan and for hours at a time. Yet the amount of plankton obtained was exceedingly small. No reason can be given why the water should not have passed through the net in large quantities during these long trips and so far as we could see it did. There was no means at hand of measuring the amount filtered and of recording the permanency of the stream entering the funnel; this is of course the vulnerable point of the evidence. Apparently, however, the apparatus worked well and continuously, and unless some reason can be found why the plankton could not enter the net, we are forced to grant that at that time of day the amount of plankton in the upper foot of water is practically *nil.** These experiments were made during the day. Unfortunately there was no opportunity to repeat them after nightfall. Surface towings were, however, made in Round and Pine lakes from a row boat after dark. With the same net, in the same way and at the same place, where in daylight a scanty collection of rotifers and algæ was made, the darkness yielded a rich haul including multitudes of crustacea. It was only the upper six to twelve inches of the water which was filtered in both cases. This evidence, scanty and incomplete as it certainly is, still points, to my mind unmistakably, to the existence of diurnal migrations on the part of the crustaceans at least. This well known occurrence in salt water has been found by Francé (94) to take place in the case of fresh water forms in Lake Balaton, Hungary; Marsh (94) has also observed it in Green Lake, Wis. In a recent publication Birge (95) denies the existence in Lake Mendota, Wis., of such migrations at least beyond the limits of three meters. I have already called attention to the fact (p. 55), that vertical migrations, carrying large numbers of a species over the limits of the artificial strata used in the lake work, would cause the compensatory fluctuations in adjacent strata as shown on the plates. It is true that if the hauls made in the Charlevoix region are plotted with reference to the time of day there does not seem to be any correlation between the time of

* While very kindly reading the proof, Prof. Reighard called my attention to the fact that he reached a similar conclusion in a paper read before the American Fisheries Society (see Report for 1892). Neither the paper nor the volume are accessible to me at date of writing.

the hauls and the variations in amount. Of course it should be noted that the hauls we made were never very late in the day and the supposed vertical migrations may have been due to entirely different causes if, indeed, they actually occurred.

I have already called attention to the compensatory fluctuations in the plankton of adjacent strata from Lake St. Clair; these are very striking if one examines the results given by Reighard for the strata of only 1.5 m. in thickness and are *more than half of them eliminated by combining the two strata 1.5-3 m. and 3-4.5 m.* Mention has also been made above of the comparative barrenness of the lower half of the stratum 1.5–4.5 m.

All of the peculiarities noted in this connection point in one direction and justify the conclusion that *the distribution of the plankton within the limits of an artificial stratum is very unequal; the variations in its distribution are probably due to vertical migration.*

One further question in vertical distribution demands brief consideration. We have seen that the amount of plankton per cubic meter of water varies inversely as the depth from which the water is obtained. Does the volume decrease constantly from surface to the bottom or is there near the latter an increase, an accumulation of forms more or less dependent upon the bottom? No exact observations were made to determine this point, but some data bearing upon the question were recorded. In the qualtiative studies made during the first two weeks on Round and Pine lakes, and Lake Michigan it was customary to have a tow taken by an ordinary surface net and and also one taken by a runner net drawn along the bottom. This was let down open through the water and drawn up open also, so that its contents were in no sense strictly bottom forms, nor was there any means of using them in quantitative determinations. It was customary to draw both this bottom net and the surface net about an equal length of time. Now while we noticed from the first that the surface net, as already mentioned, obtained but a small amount of material, chiefly Rotifera and Protozoa, it was also remarked that the bottom net brought up a host of specimens, and that these were almost entirely Crustacea. The mass of material was composed, as examination showed, of only a few species, but these few were present in such enormous numbers of individuals as to make the catch a veritable "soup." In my daily note book this richness of the bottom tow was commented on for days until we recognized it as a constant occurrence and among the notes I find the statement that the tow appeared as rich in quantity as any evening surface tow on the ocean. I was in fact thoroughly astonished to find such masses in fresh water catches. There was practically an entire lack of the numerous insect larvæ which make the volume of some fresh water hauls so great; the tow consisted of almost nothing but myriads of Copepoda. Now these were either migrants from the superjacent water or permanent residents of a zone near the bottom. The vertical hauls gave no evidence of the existence of this mass of Crustacea near the bottom, although the hauls were made at the same place and at corresponding times of day. I wish to point out here some faults in this negative argument and to emphasize the fatal error in placing entire dependence upon hauls of a *vertical* net. In the first place the impervious canvass cone brings the actual opening of the net about 40 cm. above the bottom when the net is actually resting upon a flat surface; stones and other objects as well as inequalities in the surface may increase this distance considerably. Again, the net is lowered to the bottom, rests there a second and is then hauled steadily to the sur-

face. The bucket hanging below makes some disturbance in the water before the cone reaches the bottom, and the strong swimming forms, such as *Limnocalanus*, and other Copepoda, would have abundant opportunity to escape from the dangerous ground above the cone, the place of greatest disturbance and hence the point from which the fugitives turn. Both of these reasons would naturally tend to lessen the number of bottom forms taken in vertical hauls. The runner net also gave evidence of a considerable number of *Mysis* near the bottom, but as might be expected they were taken only rarely and by twos or threes in the vertical net.

This is the vertical distribution characteristic of the warmer season of the year when, not only in respect to light but also in regard to temperature, the surface stratum is much the most favorable portion of the water for growth. In regard to only one of these factors do the conditions remain the same throughout the year, the light supply is uniformly greater at the surface in all seasons, but during the fall it is known that the temperature of the water becomes more and more uniform throughout and finally in the winter the deeper strata are actually warmer. I know of only one observation as to the effect of this change in temperature on the relative populousness of the various strata. Birge (95, p. 480), records that during the fall the distribution becomes more and more uniform throughout the water and that the surface stratum does not show any superiority in the amount of plankton present in it. If this be confirmed for other bodies of water it will be evidence that the factor of temperature has more effect on the distribution of the plankton than the light.

No opportunity has yet been found for qualitative work on the hauls of the vertical net. The counting of such a mass of material would involve more time than it has been possible for me to devote personally to that purpose and no other opportunity has yet offered itself. I am personally skeptical of the value of enumeration under ordinary circumstances and most of all of such efforts as are not extended throughout the year to afford a basis for estimating the rise and decline of various species.

It is evident of course that not all the plankton is equally valuable as fish food and not all of it seems directly or indirectly to form marketable fish. As has already been mentioned the Crustacea form the most important element from the standpoint of the fish culturist. While I with the assistance of one or more members of the party, was taking hauls with a vertical net at one side of the boat, Professors Birge and Marsh with some assistance were securing stratal hauls of Crustacea alone at the other side of the tug. Each of these gentlemen, who contributed so much to the results of the work in other directions also, brought with him a specially constructed closable net of his own designing so constructed that it could be lowered, closed, opened, raised a given distance, closed again and brought to the surface. One of the nets has already been described (Birge 95, p. 423) and the other will be shortly. At times both of the nets were used together and again a series of hauls was made with one only. The coarser cloth used in the net, the smaller amount of material obtained and the greater rapidity with which a pure crustacean haul filters, made it possible for them to secure a series of hauls from 2 and 5 meters and then every ten meters to the bottom even in the deepest places, in the same time that was consumed in making with the vertical net the series of hauls already described. These hauls are to be counted in the simplified method described by Birge (95), and will make an exceedingly valuable contribution to the vertical distribution of this most important element of fish food contained in the plankton.

SWARMS IN THE PLANKTON.

In the preceding pages an effort has been made to show uniformity of horizontal distribution of the plankton as a whole and the absence of such accumulations as might be termed "swarms." From the evidence obtained here and elsewhere I am led to believe that swarms of the entire plankton do not exist and furthermore I can see no variations of biological conditions which should accumulate *all* the life in the water within certain areas, large or small, and leave other areas more or less devoid of life. Even on the land where conditions are so much more variable that environment in the water is relatively stable, no such local accumulations are found. It is true that areas of considerable extent are more densely populated than other parts of the land, and the jungles of the tropics, for instance, are sometimes said to "swarm" with life. In the same way Agassiz (88) speaks of that portion of the continental slope and of the opposite island slope which is washed by the Gulf Stream as crowded with life. In these and similar instances there is a comparison of considerable areas with distant portions equally large. This is not in the least parallel with what some have believed to be plankton swarms. Investigators have declared that within the narrow limits of small bodies of water and frequently at points proximate to each other the total amount of plankton varies so greatly as to warrant the assumption of contiguous populous and barren areas in the water, that is the existence of swarms of the entire plankton. Now the work of Reighard in Lake St. Clair and Apstein and Zacharias in Holstein lakes and the results of this work on Lake Michigan have shown clearly, in my opinion, that this is not the case. In the preceding pages is given evidence that the total amount of plankton does vary, but that it varies in accord with the depth and that beyond this there are no variations considerable enough to warrant the assumption of the existence of swarms of the plankton as a whole. It would not be strange if the exact amount of plankton varied, perhaps considerably, at the two ends of Lake Michigan and certainly some shallow plant-filled lakes in the vicinity of Charlevoix and in free communication with the main lake by small yet perfectly open channels do contain a much larger amount of plankton than Lake Michigan itself, yet the first possible variation is as little evidence of swarms as the latter.

How do the separate species conduct themselves in this respect? Are they also nearly equally distributed, or is there reason to think that they may occur in swarms? The inequality in seasonal distribution of various species is well known. Thanks to the work of Zacharias a considerable number of species have been watched from day to day and it seems clear that most forms pass through one or more cycles of variation in each year. Such a cycle includes a period of advance, of increase in numbers, a maximum, a time of decline and decrease in numbers, and finally a minimum, or often a period of total disappearance from the plankton. These cycles are coincident with seasons or changes in temperature. Birge (95) has recorded similar variations for species in Lake Mendota. Such variations as these are characteristic of entire bodies of water, or at least very large areas in a body of water. The species appears everywhere almost at once and its disappearance is similarly general. It is not evidence of swarms to record, as Zacharias does (95, p. 120 *ff.*), that a certain species was abundant in one place and wanting on the other side of a long island which almost completely divided the lake into a northern and a southern half. It

must first be shown that the conditions which determine the development of the species, temperature, food, etc., are alike in both places, and no evidence on these weighty questions was sought or furnished. But even then it is as little evidence on species swarms as the fact that a certain fish may be caught in plenty here and is lacking there is proof of that that particular fish goes in schools!

The word "swarm" seems to need a more precise definition in the light of conditions known and easily observed. To my mind it is some such massing of individuals as is seen in a school of fish, a flock of birds, a herd of wild cattle. The idea is certainly not precise in quantity since any one of these aggregations may consist of only a few individuals or of many hundreds. They are, however, definite bands collected for breeding or feeding purposes, or for protection, or having been produced by excessive multiplication, they still remained in a localized mass. If this be a correct interpretation of conditions, then neither those accumulations of plankton or single species made at certain points by the chance of wind or current, nor yet these normal variations in the number of any species within a given area due to the more favorable environment, can be properly spoken of as *swarms*.

Recurring to conditions on the land we see that swarms of the entire plankton are not to be expected and in fact the possibility of such may well be doubted. In making only quantitative determinations of the plankton species swarms, if existing, are apt to escape notice or even to be masked by the normal variations in the total amount, by errors in method, apparatus, or manipulation and by the alternation of swarms of different species. Furthermore it is certain that if such swarms do exist there is a constant tendency to destroy them in the action of winds, waves and currents.

A species swarm will affect the total volume of plankton very little, i. e., not noticeably in contrast with other variations, if the species is ordinarily very common, if it is of small size or if it is one of many species (*polytonic* plankton). On the other hand the total volume of the plankton will be considerably affected if the species swarming is of large size, commonly rare, or if the plankton is *monotonic* (composed of but few species). Of course all grades between these two extremes are possible and a considerable factor will be the size of the swarm i. e., the number of individuals of which it is composed.

The evidence heretofore collected as to the existence of species swarms seems to me insufficient. So for instance the enumeration of a certain species taken in a haul from a depth of 40 m. shows at one time 400 individuals, at a second haul 1,100, a considerable increase to be sure, but not such evidence as to establish the occurrence of swarms. If it be true that the species is equally distributed over the entire depth, and the contrary is not even suggested in the context, then every cubic meter held at the time of the first haul 10 individuals, at the second 28. One section of land holds now 10 cattle, later 28; where is the evidence of herds? It is evident that actual proof of the occurrence of swarms demands more exact and detailed evidence than has yet been furnished. We collected no positive evidence upon this point, but one circumstance tends to my mind to establish the probability of the occurrence of swarms under some circumstances. During one of our trips on Lake Michigan the runner net was drawn over a certain area of ground off Fisherman's Island several times. Each haul brought up a good catch of crustacea, but in one there was such

a mass of *Limnocalamus* that they formed a solid mass of several ccm. The number was fifty or one hundred times greater than that obtained in the other hauls. That this was the result of including some local aggregation of the species, i. e., some swarm, is the most evident, if not the only explanation of the case. On another day Mr. Jennings reported a mass of *Asplanchna* at the surface just off the lighthouse pier so great that thousands could be taken at every haul of a net thrown from the pier. A few hours later not one was there. This may have been, however, a wind collection or even a current collection. Of course the surface is peculiarly liable to such aggregations by the effect of wind or current and the deeper water more independent of such influences.

PINE LAKE.

The town of Charlevoix is built on a narrow neck of land which separates Lake Michigan from Pine Lake (see map). The circular basin of Round Lake, which affords a fine harbor for the shipping and fishing industries of the place, lies nearly half way between the lakes first named, and is in free and open communication with both by channels of considerable size. The laboratory was located on the shore of Round Lake near the building in use by the Michigan Fish Commission as a hatchery, and the situation naturally caused us, in making the preliminary studies, to turn our attention first to Round Lake and then to Pine Lake and Lake Michigan. In the course of these studies some features of interest were manifested by the comparison of the three bodies of water, and these were supplemented by some special observations on the part of the botanist of the party, Mr. Thompson. From their importance in connection with the general question of fish culture, certain of the biological characteristics deserve brief consideration here.

Round Lake, a scant half mile in diameter, is little more than an enlargement in the course of the stream by which Pine Lake empties into Lake Michigan. The connection between these lakes has been modified for commercial use by dredging, so that now a five meter channel, protected externally by piers and a lighthouse (see map), connects Round Lake with Lake Michigan. Between Pine Lake and Round Lake the old stream, which has been entirely replaced by a straight dredged connection, lies at one side, a shallow tortuous brook, known as the "Old Channel." The broad, deep and straight artificial channel renders communication between the lakes very free and a current runs indifferently in either direction, depending upon the direction of the wind, and no doubt also on the level of Lake Michigan and Pine Lake. This results, of course, in more or less of a mixture of the forms of life, especially of those plankton species which occur in the two.

Round Lake is simply intermediate ground, and in the character of its plankton resembles now the one, now the other of the larger lakes so that it possesses no characteristic features in distinction from them. With the docks which line a large part of its shore and the continuous disturbance and pollution of its waters, there is little opportunity for the development of aquatic plant life; yet those portions of the lake which offer any possible

foothold are fairly well supplied with water plants, noticeably the shallow banks and the quiet waters of the old channel.

Pine Lake is a body of water in which, as in Lake Michigan, conditions are very stable. The area which drains into it is evidently limited, as a glance at the map will show, and the size of the lake itself is such that the inflow and outflow form but a small percentage of the total volume. There is a current running into the lake at the outlet quite as frequently and quite as powerfully as there is in the opposite direction. The shore is, in large part, sand and gravel for a short distance from the margin, but nearly the whole bottom of the lake is composed of marl, in which one finds a host of shells in good preservation. From washings of the marl, Mr. Walker identified the following forms:

Limnæa desidiosa Say.
catascopium Say.
sp.
Physa integra Hald. (young).
Planorbis bicarinatus Say.
parvus Say.
Valvata tricarinata Say.
sincera Say.
Amnicola porata Say.
lustrica Pils.
Goniobasis livescens Mke.
Sphœrium striatinum Lam.
simile Say.
Pisidium abditum Hald.
sp.
Unio luteolus Lam. (dead).
sp. (dead).
Anodonta (young) (dead).
Footiana (?) Lea.

He adds concerning these shells: "A very few of the *Amnicola* and *Valvata* were alive. Everything else was dead and most of it had the chalky appearance of fossil specimens from the marl."

On the marl one finds no living thing save here and there scanty tufts of dwarfed *Chara*, which was never found in fruit; it was uniformly encrusted by a heavy calcareous coating.

The absence of plants along the shore in the shallow water and on the sandy or gravelly bottom is also noteworthy. Isolated patches do occur but they are thrifty and abundant only in a few places, the most prominent of which are on the south arm of the lake. It will be noticed that the axis of the main lake lies directly in the path of the northwest winds and it has occurred to me that this may be the cause of the absence of shore vegetation, since the wash along the shore of a lake as large and deep as this would be too powerful to allow the growth of plants even where the bottom was of a suitable character. In the smaller and more protected south arm there is a much larger amount of vegetation. We were unable to make any exact observations in that part of the lake.

Pine Lake has undoubtedly undergone some considerable modifications within recent geological times. The old outlet to the northward is easily traced through a line of tamarack swamp to Susan Lake; thence to Lake Michigan it follows a small stream which is at present the outlet of Susan Lake. The marl bottom which underlies a very considerable part of Pine Lake can by borings be found not far below the surface at various points around the lake. The gravel and glacial drift are evidently at present being washed out into the lake over the marl and the thickness of the layer decreases gradually as one recedes from the shore. Mollusca are not very abundant and while the species recorded by Mr. Walker are recent and most of them at least found in this locality at present, the existing conditions are inadequate to account for such a bed of marl and I am inclined to believe it the bed of an older lake now gradually disappearing.

The importance of these considerations is evident when we come to examine the fauna and flora of the lake.

I have already mentioned the striking lack of vegetation, both littoral and bottom. Mr. Thompson, who spent some time in a careful examination of the shore says in this connection, "The entire absence of *Myriophyllum*, *Utricularia* and the aquatic species of *Ranunculus* is perhaps significant. The scarcity of plants is apparently due to the marl bottom as all the fairly thrifty plants which do occur are found growing on bottom more or less modified by deposits of sand or alluvial sediment." Similar mention of the limited amount of life discovered in Pine Lake may be found in the reports on the Protozoa (p. 81), Rotifera (p. 88), and Mollusca (p. 98), published in appendices to this paper. Of the insect fauna Dr. Wolcott writes:

"This poverty of the Pine Lake fauna was in marked contrast to the richness of that of the neighboring small inland lakes, in which was to be seen both in respect to number and identity of species and abundance of individuals, a marked similarity to that of Lake St. Clair, indicating the effect of the like conditions, while at the same time it emphasized the contrast between both and Pine Lake."

The plankton studies on Pine Lake discussed on a previous page and plotted on Charts I^B and II^B, show that the surface stratum contains if anything somewhat more plankton than the same portion of Lake Michigan but the deeper strata very much less, so that in shallow water (VIII) the total amount of plankton is approximately the same as in Lake Michigan while in the deeper water (XXVI to VII) the total amount is far below that in the main lake.

After this resumé of other groups it will not be strange that fish are scarce in the waters of Pine lake. Neither those of Lake Michigan nor the species which inhabit the surrounding inland lakes would find any considerable supply of nourishment and in fact a few game fish, in the south arm chiefly, and a few whitefish in the eastern end of the main lake, are all that are reported for this body of water. The absence of a bottom flora and fauna, the scarcity of plankton and the paucity of littoral vegetation with the accompanying forms of life, particularly insect larvæ, are the factors which limit the introduction of various kinds of fish.

I have discussed the conditions here in full since it seems to me a powerful argument for the necessity of employing the experimental method. Such a magnificent lake with miles of shore and acres of beautiful clear water affords possibilities for existence to a multitude of fish. The reasons for their non-existence are apparently clear, and if so the problem is half solved. In some way more vegetation must be made to grow in the lake, perhaps different species of plants introduced. If forms can be found which are capable of growth and increase on a marl bottom, the fish producing power of the lake will be multiplied enormously and in the place of a scanty population the waters will support large numbers of valuable food fish. I have endeavored to ascertain the species of water plants which thrive upon marl bottomed lakes elsewhere, but the question proved to be beyond the facilities at my command. This offers under favorable circumstances a rich field for experimentation.

CONCLUSIONS.

In addition to the more special conclusions stated in connection with various topics there are some general conclusions, especially with reference

to the plankton and its bearing on fish culture, which are summarized as follows:

I. The plankton is the source of food supply for all lake fish; its rapid reproduction affords a constant supply in spite of continued destruction.

II. The amount of plankton in Lake Michigan in the region examined is limited. The enormous area compensates for this limited amount.

III. The plankton is uniformly distributed horizontally. At this season of the year it is accumulated near the surface, and very little is contained in water below a depth of 25 meters, except that a second accumulation near the bottom is probably usual. At this season, then, no fish will be found regularly or in numbers in the nearly barren intermediate water below 25 m., except it be in the water near the bottom.

IV. The uniform horizontal distribution of the plankton indicates that the plankton-eating fish find food in limited quantities everywhere.

V. The bottom flora and fauna are not extensive enough to support large numbers of bottom feeding fish within circumscribed areas. The well known migrations of whitefish schools along shore seem thus to be correlated with the non-localized food supply.

VI. There is a plentiful supply of whitefish food on the old fishing grounds. No reason can be assigned for the diminution in the supply of whitefish save overcatching.

In conclusion I should like to emphasize one point which seems to grow clearer as the work proceeds; if the experience of two years has shown anything, it has demonstrated that the possibilities in this line of investigation can hardly be limited, but that future developments which are so essential to the fisherman and the fish culturist alike, are distinctly dependent upon the facilities for carrying on the investigation under permanent conditions.

It may be hoped that something has been accomplished during the two years of this work inaugurated under the auspices of the Michigan Fish Commission and carried on by voluntary and hearty cooperation on the part of various scientific workers. Yet it is evident that progress along this line will be necessarily slow and that at times, as in the present instance, other peremptory duties will encroach upon the time of the workers and delay the publication of the reports. Furthermore, no one can appreciate so well as one who has tried it, how enormous is the mass of work connected with an enterprise inaugurated in a new field of work, and compelled to originate at once methods and appliances with repeated delay and even failure.

It is equally true that the possibilities of future development will be clearest to those who have taken a part in the enterprise. Yet others can not fail to apprehend its importance and the necessity of continuing it. To my mind it is clear that in order to attain its proper results the work must be put on a definite basis. It must be rendered permanent and placed in the immediate charge of workers who shall devote to it their entire time. If any measure of success has accompanied it in the past while it has been under the direction of those whose time was necessarily limited or when perhaps it has been carried out as a side issue in connection with the regular work of some fish hatching station, it is none the less true that it demands and deserves the full attention of able and trained investigators.

There should also be mentioned in this connection the mass of experimental work which must be done. It is of vital importance for the solution of problems which present themselves in connection with the

biology of the lakes and their inhabitants, that experimental investigation should be possible in order to test the results, to answer questions, and to suggest possibilities that would otherwise remain undeveloped. No one can have read the preceding pages without having appreciated continually the questions suggested in connection with the most varied topics; no one can fail to see that the results attained should be supplemented or controlled by experiment.

The life of the young white fish, its food and growth while in the state of nature, the best age and place for planting, and hundreds of other questions which suggest themselves in connection with this particular topic cannot be decided in a few weeks work of a summer party however well equipped and located. Questions with reference to the yearly variations in the plankton and those problems suggested in connection with the discussion of these questions early in the report, cannot be solved until a permanent biological station shall be able to observe and to experiment continuously throughout the year. Already efforts have been made on a limited scale at least, towards the increase and multiplication of the food supply of fresh water fish and in some small ponds of Europe it has met with moderate success. The discussion of Pine Lake suggests an equally fertile field of study. The possibilities of the future are evidently dependent upon the possibilities for investigation and experiment. Aquaculture must be given the same sort of scientific treatment that agriculture already receives at the hands of the thousand trained investigators in experiment stations that are located in every state of the Union. It must be studied from the same scientific standpoint; its problems analyzed, its course marked out definitely; not until then can it render that service to the people which the opportunity of our inland seas makes possible in the way of a food supply at once cheap and agreeable. Let me quote from an address before the American Microscopical Society: "Fish culture will never attain its proper results until it receives by the liberality of the State and nation the same favors that have been extended to agriculture, the use of permanent and well equipped experimental stations where trained workers shall devote all their time and energy to the solution of its problems. The Great Lakes furnish a cheap and valuable food supply to one-third of our entire population, This food supply is rapidly becoming depleted. How long must such important interests wait their just recognition and adequate protection? And if properly developed, who can limit the possibilities of these Inland Seas in supplying the nation with food?" The urgent need of the present is not a mere biological observatory, however valuable such a permanent foundation might be, but a well-equipped and well-directed experiment station to attack the peculiar problems of fish culture in the Great Lakes.

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NOTE—Since the earlier pages of this report were in print there has appeared "The Lakes of North America" by I. C. Russell; Ginn & Co., Boston, 1895. This gives (p. 57 to 63) physical data on the Great Lakes more fully and accurately than any authority previously at my command. The figures quoted on pages 8 and 9 of this report should be slightly modified, but the argument and conclusions are in no way affected. Much additional information of interest on the physical features of the lakes may also be found in the work cited.

APPENDIX I.

REPORT ON THE PLANTS.

BY H. D. THOMPSON, MOLINE, ILL.

For the three weeks beginning August 2, 1894, it was the good fortune of the writer to be with the investigating party maintained at Charlevoix by the Michigan State Fish Commission. During this time there was made some study of the minute plant life of Lake Michigan and a botanical survey of Pine Lake was begun. The time did not suffice for the proper handling of either task.

Pine Lake is a marl bottomed basin of a type not rare in northwestern Michigan. Unlike many of the small lakes which line the shore of Lake Michigan, its greatest length, instead of lying parallel with the adjacent shore line of the larger lake, forms with it a large angle. Some fifteen miles long and in its broadest portion three miles wide, and very irregular in outline its shore line exceeds ninety miles. Its western end is rather more than a mile from Lake Michigan with which it communicates freely through Round Lake. The natural water ways from Pine Lake to Round Lake and from the latter to Lake Michigan have been so improved for purposes of navigation by large lake boats, as to render communication much freer now than formerly.

The shore of the lake rises in two bold terraces which appear with much regularity and clearness at Belvedere, and though sometimes broken, in places effaced by erosion, and often lying at considerable distance from the present shore line, they may still be traced along the lake for long distances to the eastward, and are continuous around Round Lake on both sides and thence along Lake Michigan both to the northward and southward.

At present the lake consists of a long, narrow, central basin twenty to twenty-five meters in depth with a uniform regular marl bottom, extending from Charlevoix at its western end to Boyne at the eastern, surrounded by shallower waters including all coves and bays and a marginal area of varying width along the shore.

The bays are all rather shallow, the bottom sloping away gradually from the shore line toward the edge of the basin, which in each case extends across the mouth of the bay in a line between points in front of the headland on either side.

In general the bottom drops off evenly until, at a distance of two hundred twenty-five to three hundred twenty-five meters from shore there is a

depth of about fifteen meters; then in course of two or three rapid casts of the lead eighteen to twenty-one meters is found, and the lead comes up bearing soft sticky marl. Exceptions were noted in which the gentle slope was continuous from the shore line, for a full half mile into the lake, before the twenty meter depth was reached. One and one-half miles N. E. of Advance a depth of twelve meters was found at fifty meters from shore; twenty meters, fifteen meters farther out, and within another twenty-five meters the lead dropped down twenty-six meters, to the end of our sounding line, but found no bottom.

The beach of Pine lake varies from sand in certain localities to calcareous gravel or even soft marl in others. The bottom of the shallow marginal portion naturally partakes of the character of the adjacent beach, but invariably shades off to a marl as deeper water is reached. In some bays surrounded by cedar swamps the bottom is of soft, blackish mud, part marl, part alluvial deposit. In a few places where a bold sandy terrace approaches the shore line closely, the bottom is of clean sand for a long distance out toward deep water.

The flora of Pine Lake is exceedingly meager. The observer may row along its shore for miles without seeing one thrifty bed of water weeds, and may dredge back and forth over a hundred acres of bottom without securing a handful of vegetation. In water varying from three to seven meters in depth were found scanty beds of *Chara* sp., never of thrifty well grown plants, never in fruit and always encrusted with calcareous material. Along shore, in water one and one-half to three meters in depth, occur a half dozen thin and rather small beds of *Potamogeton perfoliatus* L. Half way up the lake on the north side, on sand bottom, was a fairly thrifty and good sized bed of *Scirpus pungens*, *Potamogeton perfoliatus* L., *Potamogeton lucidulum*, *Naias flexilis* and *Chara* sp. In the edge of this bed toward deep water several fishing stakes were noticed.

Some bass fishing being reported in Oyster bay on the south side of the lake, it was examined with some care. Oyster bay is an arm of the lake a half mile wide and nearly one and a half miles long. At the mouth the bottom slopes gently away from the shore on either side to a depth of nine meters near the middle. It becomes shallower steadily as its head is approached, ending in a marsh which shades off to the surrounding cedar swamp. Separated from this bay by a stretch of cedar swamp lies Susan Lake. In Oyster bay the bottom is of marl and black sediment mixture previously mentioned and vegetation is more plentiful than we found it elsewhere in the lake. A mile or more of shore line about the head of the bay is fringed with thrifty beds of *Scirpus pungens* Vahl., and *Scirpus lacustris* L.; *Potamogeton perfoliatus* L. occurs in several places. *Acorus calamus* L. and *Typha latifolia* L. also occur here though not noted elsewhere in the lake. The bottom bears numerous and fairly thick beds of *Chara* sp., the same as found elsewhere in the lake. There was everywhere a striking scarcity of algæ and the entire absence of *Myriophyllum*, *Utricularia* and aquatic species of *Ranunculus* is noteworthy.

The examination of material collected by tow net and dredge from the neighboring waters of Lake Michigan, Round Lake and Pine Lake for minute life, which had been in progress for several weeks, was near completion at the time the writer became a member of the Fish Commission party. Material was examined, however, and data collected, sufficient perhaps to indicate certain obvious facts, though not sufficient foundation for any complicated or detailed conclusions.

As might be expected from the free communication between Lake Michigan and the smaller lakes, the three lakes vary little in flora. The open, wind agitated waters, unobstructed by the larger aquatic plants, and for the most part of considerable depth, afford but poor harbor for the filamentous algæ, Desmidiæ and Characeæ so abundant in the waters of Lake St. Clair investigated by the commission in 1893. The tow net and dredge, therefore, collect but little of such material, but the Diatomaceæ are ever present.

Of the algæ *Pandorina morum* Bory., is most frequently met, occurring chiefly in surface tows, sometimes in great abundance. The stray specimens noted in deep tows may have been taken by accident, as the net was lifted from the water. Bottom tows and dredgings in Lake Michigan show fine colonies of *Nostoc commune*. *Vaucheria tuberosa* also is common clinging to rocks, waterlogged bits of wood, etc., often at considerable depth It occurred in great abundance on fishing grounds off High Island, with *Chara* sp., the dredge teeth soon becoming entangled with bushels of this mixed material. In Pine Lake the surface net not infrequently collected bits of *Spirogyra* sp., *Zygnema* sp., *Oscillaria elegans* Ag., *Lyngbya* sp. The fragments were always quite small, generally so far gone to pieces as to be of doubtful identity and were probably from beach pools washed into the lake by receding waves during high wind.

The Desmidiæ were not represented in any material examined from Lake Michigan, Round Lake or Pine Lake. In a surface tow from Twin Lakes, the following were noted:

Cosmarium brebissonii Menegh.
C. marginatum Menegh.
C. reniforme.
C. subcrenatum Hantzsch.
C. undulatum.
Pediastrum ehrenbergii Corda. (H. Br.).
Sphærozasma filiforme Rab.
Staurastrum corunulatum Wolle.
S. grallatorium Nord.

The Diatomaceæ, greatly outnumbering all other plants both as to species and individuals, force themselves constantly upon the attention of the botanist. Individuals are generally present in much greater numbers in deep than in surface tows, but the distribution of species appears to be influenced but little by depth of water. The stipate forms are of course more often found in the neighborhood of a congenial support, but with little regard to the depth of this support below the water surface. The following species were noted, most of them in great numbers:

Asterionella formosa Hass., common in both surface and deep tows.
Cocconema lanceolatum Ehr., frequent in dredgings.
Coscinodiscus radiatus Ehr., occasional among weeds.
Cyclotella rotula Kütz., in dredgings, infrequent.
Cymbella gastroides Kütz., common in deep and surface tows.
Cystopleura gibba (Ehr.) Kütz., common in surface and deep tows everywhere.
Navicula viridis (Nitzsch.) Kütz., common on weeds in shallow water.

Nitzschia dubia Wm. Sm., single specimen, among weeds near surface.
Nitzschia sigmoidea (Nitzsch.) Wm. Sm., in surface and deep tows.
Epithemia turgida Wm. Sm.
Fragilaria capucina Desm., deep and surface tows, very common.
Gomphonema geminatum (Lyng.) Ag., surface and (more often) deep tows.
Orthosira sp., like *O. Dikii* Wm. Sm., once in surface, once in deep tow.
Stauroneis phœnicenteron Ehr., deep tow.
Synedra affinis Kütz., surface and deep tows.
S. lunaris Ehr., among weeds in shallow water.
S. ulva (Nitzsch.) Ehr., in dredgings.
Tabellaria fenestra (Lyng.) Kütz., common everywhere.
T. flocculosa (Roth.) Kütz., common.

Washings from aquatic plants are, as is well known, generally rich in Diatomaceæ. The following species identified by D. B. Ward, M. D., of Poughkeepsie, N. Y. are from a small vial of material washed from *Chara* sp., previously mentioned as being dredged from the bottom in High Island harbor, Lake Michigan.

Achnanthidium flexellum.
Amphora ovalis.
Campylodiscus novicus.
Cocconeis placentula.
Cocconema cistula.
C. gastroides.
C. lanceolatum.
C. cymbiforme.
Cyclotella compta.
Cymbella ehrenbergii.
Encyonema limula.
E. prostratum.
E. turgidum.
Epithemia argus.
E. gibba.
E. turgida.
Eunotia arcus.
E. diodon.
E. pectinalis.
Fragilaria Harrisonii.
F. capucina.
Gomphonema capitatum.
G. constrictum.
G. coronatum.
G. intricatum, var. *pumilla.*
Melosira granulata.
Navicula affinis.
N. bacillum.
N. limosa.
N. oblonga.
N. nobilis.
N. radiosa.
N. perigrina.
N. trinodis.
N. viridis.
Nitzschia frustulum.
N. palea.
Odontidium hyemale.
Pleurosigma attenuatum.
Surirella bifrons.
S. biseriata.
S. elegans.
Stauroneis gracilis.
S. phœnicenteron.
Stephanodiscus astrea.
Synedraulna, var. *longissima.*
Tabellaria fenestrata.
T. flocculosa.

The writer desires to acknowledge his obligation and express his thanks to D. B. Ward, M. D., of Poughkeepsie, N. Y., for the identification of the above list of diatoms and to Mr. C. F. Wheeler, of Michigan Agricultural College, who has identified a considerable number of flowering plants.

APPENDIX II.

A REPORT UPON THE PROTOZOA OBSERVED IN LAKE MICHIGAN AND THE INLAND LAKES IN THE NEIGHBORHOOD OF CHARLEVOIX, DURING THE SUMMER OF 1894.

BY C. A. KOFOID, SUPERINTENDENT OF THE BIOLOGICAL STATION OF THE UNIVERSITY OF ILLINOIS, URBANA, ILL.

The observations in the following paper were made in the laboratory of the Michigan Fish Commission at Charlevoix from July 24 to September 1, 1894. The material examined consisted in the main of collections made at the surface and bottom, with fine muslin nets, principally in Pine and Round lakes and Lake Michigan. In addition to these, shore collections were made along Round, Pine, Susan, Twenty-six, East and West Twin lakes, either by dragging the Birge net through the weeds along the shore, or by gathering the vegetation—algæ, *Chara*, *Naias*, *Utricularia*, *Potamogeton*, *Myriophyllum*, and *Nuphar*—and keeping it in aquaria in the laboratory, or collecting "washings" from it for immediate examination. To the systematic examination of these shore collections but little time could be given as the plankton was the main object of our investigation.

The present paper makes no pretension to completeness. It is merely a list, a compilation from the daily record of the occurrence and distribution and relative abundance of such species as were identified during the six weeks of my stay at the laboratory. Many of the smaller Flagellata and Ciliata were not identified and no attention was paid to the Gregarinidæ and little to the ecto and endo-parasitic Protozoa of the denizens of the lakes examined. The present report does not include the collections made with the plankton net in Lake Michigan, nor those made by Dr. R. H. Ward with the Birge net in the lakes to the north of Charlevoix as these collections have not yet come into my hands. A continuous and more thorough investigation would undoubtedly greatly extend the list of Protozoa here reported for the locality. A few forms were found which could not be referred to any described species in the literature at hand.

The appended list records 81 forms, 76 species and five varieties. The list reported by Smith (Bulletin Michigan Fish Commission No. 4, 1894), for Lake St. Clair includes 32 forms, eighteen of which are to be found among those observed at Charlevoix.

The forms included in the present list are distributed as follows among the different groups:

Rhizopoda	22
Heliozoa	5
Mastigophora	20
Infusoria	34

RHIZOPODA.

1. *Amœba proteus* Leidy. Swampy shores of Pine Lake, and West Twin Lake. Not common.
2. *Amœba radiosa* Ehrbg. Swampy shores of Pine Lake. Rare.
3. *Amœba verrucosa* Ehrbg. Among the algæ along the shores of Pine Lake. Not common.
4. *Cochliopodium bilimbosum* Auerbach. A single specimen from washings from *Chara* obtained at High Island harbor was observed. The collections came from a depth of about 6 m. on whitefish grounds.
5. *Arcella vulgaris* Ehrbg. Twenty-six Lake, East and West Twin lakes, in shore collections. Occasionally found in the surface and bottom tow in Round Lake. Common in *Sphagnum*.
6. *Hyalosphenia elegans* Leidy. Common in *Sphagnum* along the shores of Pine Lake. Single specimen taken in surface tow at West Twin Lake.
7. *Hyalosphenia papilio* Leidy. Common in *Sphagnum* along shores of Pine Lake.
8. *Quadrula symmetrica* F. E. Schultze. Common in *Sphagnum* along shores of Pine Lake.
9. *Difflugia collaris* Ehrbg. Common among *Fontinalis* from shores of East Twin Lake.
10. *Difflugia constricta* Ehrbg. In shore collections from Twenty-six Lake. Rare.
11. *Difflugia globulosa* Duj. Occasional in shore collections at East and West Twin Lake and Twenty-six Lake; in *Sphagnum* along Pine Lake. Common in surface and bottom tows and hauls of the plankton net in Round and Pine lakes and especially in Lake Michigan. It is much more abundant in surface than in bottom tows and in Lake Michigan than in the smaller lakes. It is very resistant, remaining active long after other animals in the tow have perished because of foul water. The limnetic form cannot be distinguished specifically from the form found in shore collections and in *Sphagnum*.
12. *Difflugia lobostoma* Leidy. Taken in surface tow in West Twin Lake in shallow water; also in bottom tow in Round Lake in 16 m. of water. Rare.
13. *Difflugia pyriformis* Perty. Occasional in shore collections along Pine and Twenty-six Lake; also in bottom tow in Round Lake in 16 m. of water and in bottom tow in Lake Michigan, 2¾ miles from shore in a haul of the plankton net in 57 m. of water.
14. *Nebela barbata* Leidy. Occasional in Sphagnum along Pine Lake. Forms intermediate between *N. barbata* Leidy and *N. collaris* Ehrbg. were also found in the same locality. (See Leidy's Fresh Water Rhizopods of N. A., Pl. 24, Figs. 18, 19.)
15. *Centropyxis aculeata* Stein. In shore collections along Pine Lake, East Twin, Twenty-six, and Susan lakes. Also in bottom tows in Lake

Michigan, 1½ miles off New York Point in 24 m., and 2 miles off Norwood in 16 m. of water. Occasional.

16. *Centropyxis ecornis* Leidy. A single dead shell was found in shore collections from East Twin Lake. This is probably a variety of the preceding.

17. *Euglypha alveolata* Duj. Occasional in shore collections along Pine and West Twin lakes, in *Sphagnum* and washings from *Utricularia.*

18. *Euglypha ciliata* Ehrbg. A single specimen was taken in surface tow off Fisherman's Island, in Lake Michigan. Common in *Sphagnum* about Pine Lake.

19. *Euglypha cristata* Leidy. Rare in *Sphagnum* along shores of Pine Lake.

20. *Trinema enchelys* Ehrbg. Common in *Sphagnum* along the shores of Pine Lake. Occurred also in shore collections from West Twin Lake. A single specimen was noted in a haul of the plankton net in 55 m. of water, 2½ miles off Norwood in Lake Michigan.

21. *Cyphoderia ampulla* Ehrbg. In shore collections from Pine and West Twin lakes. Common, especially in *Sphagnum.* Occasionally found in bottom tows in Round Lake and once in Lake Michigan 2¾ miles from shore in a haul of the plankton net in 57 m. of water.

22. *Gromia mutabilis* Bailey. Common on floating colonies of *Ophrydium versatile* in East Twin Lake.

HELIOZOA.

23. *Vampyrella laterita* Fres. Rare, in shore collections from East Twin Lake and Twenty-six Lake, among algæ or on masses of *Ophrydium versatile.*

24. *Actinophrys sol* Ehrbg. Lake Michigan, Pine Lake, Round Lake, West Twin Lake. More abundant in surface than in bottom tows. Found also in shore collections. Common.

25. *Actinosphœrium Eichhornii* Ehrbg. Bottom tow in Round Lake, also in bottom tow in Lake Michigan, N. W. of Norwood, two miles from shore in 15 m. of water. Rare.

26. *Heterophrys myriapoda* Archer. Rare among algæ in pools along Pine Lake.

27. *Rhaphidiophrys viridis* Archer. In shore collections from East and West Twin and Susan lakes. Rare.

MASTIGOPHORA.

28. *Dinobryon sertularia* Ehrbg. The type as figured and described by Bütschli and Kent, is much less common than the varieties. It occurs however in surface and bottom tows in Round Lake and Pine Lake and in Lake Michigan, and in shore collections at West Twin Lake.

29. *Dinobryon sertularia* Ehrbg. var. *angulatum* Seligo. Most common of all varieties, occurring in surface and bottom tows in West Twin, Round, and Pine lakes and Lake Michigan.

30. *Dinobryon sertularia* Ehrbg. var. *divergens* Imhof. Very common in surface and bottom tows in Round and Pine lakes, and in Lake Michigan.

31. *Dinobryon sertularia* Ehrbg. var. *undulatum* Seligo. Common in Round and Pine lakes and in Lake Michigan in surface and bottom tows.

32. *Dinobryon stipitatum* Stein. Common in surface and bottom tows in Round and Pine lakes, most abundant in Lake Michigan. Intermediate forms connect this with the preceding species, and it should perhaps be reduced to a variety.

33 *Uroglena volvox* Ehrbg. Common in surface and bottom tows in Round and Pine lakes and in Lake Michigan.

34. *Euglena viridis* Ehrbg. Common in shore collections along Pine, East Twin and Twenty-six lakes. Also found occasionally in bottom tow in Pine Lake at a depth of 15 m.

35. *Entosiphon sulcatum* Stein. Among algæ in pools along the shore of Pine Lake; common.

36. *Synura uvella* Ehrbg. Occasional in surface and bottom tows in Round and Pine lakes and in Lake Michigan.

37. *Mallomonas acaroides* Zach. In surface tow in shallow water in West Twin Lake; also in bottom tow in Pine Lake in 13 m. of water; occurring in both cases with the following variety; rare.

38. *Mallomonas acaroides* Zach., var. *producta* Zach. Common in bottom tows from Pine Lake, Aug. 4, but not found again during the summer except in small numbers in surface tow at West Twin Lake on Aug 6. Cysts were forming Aug. 4, and no individuals intermediate between the type and the variety were noticed in the material examined.

39. *Gonium pectorale* Ehrbg. Occasional in bottom tow in Pine Lake.

40. *Pandorina morum* Ehrbg. Occasional in surface tows in Lake Michigan.

41. *Volvox globator* Ehrbg. Rare in bottom tow in Round Lake.

42. *Diplosiga frequentissima* Zach. Common in surface and bottom tows in Round and Pine lakes and Lake Michigan on *Asterionella*.

43. *Chilomonas paramœcium* Ehrbg. Very abundant in shore collections which had stood in laboratory for several days. *Paramœcium aurelia* had been abundant in the same jars on previous day but decreased rapidly in numbers as *Chilomonas* multiplied.

44. *Peridinium tabulatum* Ehrbg. Frequent in surface tows in Lake Michigan, also in surface tow in West Twin Lake, and surface and bottom tows in Round Lake. Taken in small numbers with the Birge net in Susan Lake.

45. *Ceratium cornutum* Ehrbg. Frequent in washings from *Utricularia* from West Twin Lake; associated with a long slender form of *C. hirundinella* O. F. Müll. with divergent horns.

46. *Ceratium hirundinella* O. F. Müll. In shore collections from Pine, Round, Susan, East and West Twin lakes, occasional. Abundant in every surface and bottom tow in Round and Pine lakes, and especially in Lake Michigan. Triangular cysts were common in bottom tows and dredge washings during the first two weeks of August. They were also found occasionally in surface tows. A wide range of variation is exhibited by this species. The horns vary in number from three to six, also in the degree of their prolongation and divergence. Individuals with deformed, curved and even hooked horns were found. One three horned specimen had the left posterior horn bifid for about half its length.

47. *Glenodinium cinctum* Ehrbg. Common in shore collections along West Twin Lake especially in washings from *Utricularia*. Also found in surface and bottom tows in Lake Michigan, and in the latter part of August the gelatinous "cysts" containing one to three individuals were

common in surface and bottom tows in Round and Pine lakes and in Lake Michigan.

INFUSORIA.

48. *Coleps hirtus* Ehrbg. In shore collections from East and West Twin lakes. Frequent especially in aquaria that had stood for some days.

49. *Trachelius ovum* Ehrbg. A single specimen observed from pool along Pine Lake.

50. *Dileptus anser* O. F. Müll. In shore collections (Birge net) in West Twin and Susan lakes. Occasional.

51. *Nassula ornata* Ehrbg. Common on colonies of *Nostoc* and Diatoms and on Phryganeid egg masses brought up in the trawl off Beaver Island in Lake Michigan from a depth of 60 m.

52. *Frontonia acuminata* Ehrbg. Rare in shore collections at East Twin Lake, associated with *Ophrydium versatile.*

53. *Uronema marina* Duj. Very common in algæ in pools along Pine Lake.

54. *Paramœcium aurelia* O. F. Müll. Very abundant in shore collections from Pine Lake that stood in the laboratory several days.

55. *Paramœcium bursaria* Ehrbg. In washings from West Twin Lake; rare. Also taken with the Birge net in Susan Lake.

56. *Urocentrum turbo* O. F. Müll. Abundant in shore collections from West Twin Lake that had been standing in the laboratory for several weeks.

57. *Cyclidium glaucoma* Ehrbg. Among algæ in pools along the shore of Pine Lake; common.

58. *Conchophthirus anodontæ* Ehrbg. On *Anodonta, Unio* and *Limnea stagnalis.*

59. *Spirostomum ambiguum* Ehrbg. Among algæ in pools along Pine Lake, occasional.

60. *Stentor igneus* Ehrbg. Abundant in Round Lake upon *Chara.*

61. *Stentor igneus* Ehrbg. var. *fuliginosus* Forbes. Very abundant blackening the margins of the pools along the shore of Pine Lake, also in Round Lake upon *Chara.* Varies greatly in size and amount of black pigment.

62. *Stentor Rœselii* Ehrbg. Rare in shore collections in East and West Twin, Susan and Round lakes.

63. *Halteria grandinella* O. F. Müll. Common among algæ in pools along Pine Lake.

64. *Strombidium turbo* C. & L. Common in shore collections from West Twin Lake that had been standing in the laboratory for several weeks.

65. *Tintinidium fluviatile* Stein. A single specimen in bottom tow from Round Lake, made in 16 m. of water.

66. *Codonella cratera* Leidy. Surface and bottom tows, Pine Lake, and especially in Lake Michigan. Frequent. This species shows a wide range of variation in size, in the relative size of the aperture and the length of the neck. The number of rings on the neck varies from one to five, though in many cases no ring at all can be detected. Many individuals show no traces of the overarching ring about the aperture of the shell.

67. *Stichotricha cornuta* C. & L. Single specimen noted in shore collections from East Twin Lake.

68. *Oxytricha æruginosa* Wrz. Among algæ in pools along Pine Lake; occasional.

69. *Stylonychia mytilus* Ehrbg. Common in shore collections from East Twin Lake.

70. *Euplotes Charon* Ehrbg. Occasional among algæ in pools along Pine Lake.

71. *Aspidisca costata* Duj. Among algæ along shores of Pine Lake. Common.

72. *Trichodina pediculus* Ehrbg. On *Hydra.* This species has been reported by Zacharias (See Zeitschrift für Fischerei und deren Hilfswissenschaften, 1894, Heft 4) as parasitic on young whitefish, as many as 25 individuals being found on 4 sq. mm. of epidermis.

73. *Vorticella rhabdostyloides* D. S. Kellicott. Abundant on floating masses of *Anabæna* in surface and bottom tows in Round and Pine lakes and Lake Michigan.

74. *Vorticella campanula* Ehrbg. In shore collections from East and West Twin lakes; rare.

75. *Vorticella nebulifera* Ehrbg. Occasional in shore collections from Twenty-six Lake.

76. *Ophrydium versatile* O. F. Müll. In East Twin and Susan lakes. Common. Colonies reaching in some cases 125 mm. in longest diameter.

77. *Cothurnia crystallina* Ehrbg. On *Spirogyra* in East Twin Lake, occasional. A single small detached form taken in the plankton net within 3 m. of the surface is probably to be referred to this species.

78. *Lagenophrys ampulla* Stein. On the branchial appendages of *Hyalella dentata* Smith, from West Twin Lake; common.

79. *Stylohedra lenticula* D. S. Kellicott. Common on the caudal setæ of *Hyalella dentata* Smith, from Twenty-six Lake and bottom tows in Lake Michigan.

80. *Dendrocometes paradoxus* Stein. One detached dead specimen was found in the shore collections from West Twin Lake.

81. *Podophrya cyclopum* C. & L. On carapace of *Epischura lacustris* Forbes.

The nature of the lakes examined by the Fish Commission party in 1894 differs strikingly from that of Lake St. Clair examined in 1893. Lake St. Clair is a shallow lake with strong currents and an abundant supply of vegetation. Lake Michigan on the other hand has deeper water, feebler currents and little or no vegetation along its shores or on its bottom. Thus of Magnin's plant zones, the *Phragmitetum, Scirpetum, Potamogetonetum* and *Characetum* the last only is represented and that too in very limited areas, at least in the parts of the lake examined in 1894. This fact necessarily profoundly influences the character of the Protozoan fauna of the littoral zone and to a slight degree at least the qualitative character of the plankton itself, as it must reduce the number of occasional migrants from the littoral zone.

The conditions in Pine Lake resemble those of Lake Michigan in the absence of littoral vegetation and the limited area of the *Characetum.* Its fine marl and sand bottom affords no support to the alluvium loving water plants. Round Lake also is devoid of any considerable amount of vegetation; only a few scattered *Potamogetons* and isolated patches of *Chara* being found.

The Protozoan fauna of these lakes falls into two divisions representing (1) limnetic fauna—found free swimming or floating in the plankton and including relatively a very small number of species—and (2) littoral fauna.

LIMNETIC FORMS, (21.)

Difflugia globulosa.
Actinophrys sol.
Actinosphærium Eichhornii.
Dinobryon sertularia.
Dinobryon sertularia var. *divergens.*
Dinobryon sertularia var. *angulatum.*
Dinobryon sertularia var. *undulatum.*
Dinobryon stipitatum.
Uroglena volvox.
Synura uvella.
Mallomonas acaroides.
Mallomonas acaroides var. *producta.*
Gonium pectorale.
Pandorina morum.
Diplosiga frequentissima.
Peridinium tabulatum.
Ceratium hirundinella.
Glenodinium cinctum.
Codonella cratera.
Vorticella rhabdostyloides.
Podophrya cyclopum.

Of the 21 species included in the above list all belong to the active limnetic groups except the following which must be classed as passive limnetic forms:

Diplosiga frequentissima (on *Asterionella*).
Vorticella rhabdostyloides (on *Anabæna*).
Podophrya cyclopum (on *Epischura lacustris*).

There is not the least doubt that *Difflugia globulosa* is a prominent and during the period of observation, July 24–Sept. 1, constant member of the limnetic fauna. Its classification as an active form is perhaps questionable. With the exception of this Rhizopod, *Difflugia*, the Heliozoans *Actinophrys* and *Actinosphærium*, and the aberrant ciliate *Codonella*, all of the active limnetic species belong to the Mastigophora, are independent of a substratum for attachment and have holozoic nutrition. They share with the few pelagic algæ and diatoms the important function of furnishing food for the limnetic Crustacea which in turn are probably eaten by fish. They are thus an indispensable factor in the economy of the organic life of the Lakes.

In addition to the species in the above list which form the greater part of the Protozoan plankton there are many species of the littoral zone which are from time to time found in the plankton.

The following forms which probably belong to the littoral fauna have been observed in the plankton and further investigation would doubtless extend the list to include most if not all of the species of the littoral fauna.

Arcella vulgaris
Hyalosphenia elegans
Difflugia lobostoma
Centropyxis aculeata
Euglypha ciliata
Trinema enchelys
Cyphoderia ampulla
Euglena viridis
Volvox globator
Cothurnia crystallina

Actinosphærium Eichhornii and *Podophrya cyclopum* are also found in the littoral zone and might be included in the list as frequent migrants. *Actinophrys sol* on the other hand must be regarded as a limnetic as well as a littoral species inasmuch as mere migration is insufficent to explain

its frequent and repeated occurrence in the waters of Lake Michigan miles from shore.

There is not sufficient evidence at hand for a distinction between the autolimnetic or surface, and the bathylimnetic or abyssal species inasmuch as the nets used for taking the bottom tow were not self closing and so called "bottom tow" included not only the bottom species but also those captured during the ascent of the net. The examination of the hauls with the plankton net will doubtless shed some light on the subject of the distribution of the protozoa in the bottom, the intermediate and the surface zones. So far as the evidence at hand goes, the indications are that the large majority of the limnetic species are found at both surface and bottom. *Difflugia globulosa* and *Actinophrys sol* are apparently more abundant in the surface tow. *Actinosphærium Eichhornii*, *Euglena viridis*, *Mallomonas acaroides* var. *producta*, *Volvox globator*, have been found mainly or only in bottom tows though all but one of these may be migrants, and all occur infrequently.

LITTORAL FORMS.

Lake Michigan has properly speaking no littoral zone. The sandy beach and the action of the waves prevent its formation and the migrants are probably carried down by the tributaries. In the case of Pine Lake however we can distinguish a slightly developed littoral zone with two distinct regions. (1) Shore pools; shallow bodies of water of small extent fed by springs. They contain a few dwarfed rushes, sedges and *Utricularias* and generally an abundance of algæ. In these pools the following species were found:

Amœba radiosa.
Amœba verrucosa.
Arcella vulgaris.
Actinophrys sol.
Vampyrella laterita.
Heterophrys myriapoda.
Entosiphon sulcatum.
Coleps hirtus.
Trachelius ovum.
Uronema marina.
Paramœcium aurelia.
Cyclidium glaucoma.
Spirostomum ambiguum.
Stentor igneus.
Stentor igneus var. *fuliginosus.*
Stentor Roeselii.
Halteria grandinella.
Oxytricha æruginosa.
Stylonychia mytilus.
Euplotes Charon.
Aspidisca costata.

(2.) Sphagnum: This is abundant in the cedar swamps (on the borders of Pine Lake) which are drained by brooks directly into the lake. In some places the *Sphagnum* comes to the water edge. Its Protozoan fauna consists mainly of Rhizopods. The following species were noted. Others doubtless occur.

Amœba proteus.
Amœba radiosa.
Arcella vulgaris.
Hyalosphenia elegans.
Hyalosphenia papilio.
Quadrula symmetrica.
Difflugia collaris.
Difflugia pyriformis.
Centropyxis aculeata.
Nebela barbata.
Euglypha alveolata.
Euglypha ciliata.
Euglypha cristata.
Trinema enchelys.
Cyphoderia ampulla.

The other inland lakes investigated had well developed littoral zones, abounding in plant life. The determination of the fauna of these lakes was confined to the examination of shore collections and this owing to the short time available for the purpose was necessarily very incomplete. Nevertheless it was here that the greatest number of species was found. The following were identified:

Amœba proteus.
Arcella vulgaris.
Hyalosphenia elegans.
Difflugia collaris.
Difflugia constricta.
Difflugia globulosa.
Difflugia lobostoma.
Difflugia pyriformis.
Centropyxis aculeata.
Centropyxis ecornis.
Trinema alveolata.
Cyphoderia ampulla.
Gromia mutabilis.
Actinophrys sol.
Vampyrella laterita.
Raphidiophrys viridis.
Dinobryon sertularia.
Dinobryon sertularia var. angulatum.
Synura uvella.
Mallomonas acaroides.
Mallomonas acaroides var. producta.
Chilomonas paramœcium.
Peridinium tabulatum.
Ceratium cornutum.
Ceratium hirundinella.
Glenodinium cinctum.
Coleps hirtus.
Dileptus anser.
Frontonia acuminata.
Paramœcium aurelia.
Paramœcium bursaria.
Urocentrum turbo.
Stentor Roeselii.
Strombidium turbo.
Stylonychia mytilus.
Stichotricha cornuta.
Trichodina pediculus.
Vorticella campanula.
Vorticella nebulifera.
Ophrydium versatile.
Cothurnia crystallina.
Lagenophrys ampulla.
Stylohedra lenticula.
Dendrocometes paradoxus.

The close similarity of the European and the North American Protozoan fauna is strikingly illustrated in the list of Protozoa observed at Charlevoix. Of the 81 forms identified at least 73 (and probably more) are also found in Europe.

Zacharias in the Forschungsberichte aus der Biologischen Station zu Plön, Theil II, lists 93 Protozoa as occurring in the Plöner See, 43 of which are contained in the present incomplete Charlevoix list. With two exceptions, *Podophrya cyclopum* and *Glenodinium cinctum*, every one of the limnetic species reported for our waters is also found at Plön. The limnetic Protozoa of the two continents are practically identical.

APPENDIX III.

REPORT ON THE ROTATORIA.

WITH DESCRIPTION OF A NEW SPECIES.

BY H. S. JENNINGS.

The Rotatoria are much less abundant in Lake Michigan and the waters connected with it, in the region of Charlevoix, than in Lake St. Clair. The limnetic species are fairly well represented, but littoral and bottom forms are rare on account of the character of the shores and bottom. These are almost everywhere of sand or clay and nearly without vegetation. The number of species found in these lakes is therefore scarcely more than half the number found in Lake St. Clair in the summer of 1893.

In some of the smaller lakes at some distance from Lake Michigan and not openly communicating with it, Rotifera are more abundant, the fauna here showing much more the characteristics of that of Lake St. Clair. The rotifers from these lakes will be reported separately, as will also a short list from the sphagnum swamps of the region.

The account therefore takes the following form:

1. List of Rotatoria from Lake Michigan and the two lakes in open communication with it (Round Lake and Pine Lake), with notes on distribution.
2. List of Rotatoria from pools on the sandy shore of Pine Lake.
3. List of Rotatoria from West Twin Lake.
4. List of some Rotatoria in material brought from Susan Lake.
5. List of Rotatoria from sphagnum swamps near Pine Lake.
6. List of species new to the fauna of Michigan.
7. Systematic and faunistic notes on certain species in the preceding lists, with description and figures of *Distyla signifera* n. sp.

1. LIST OF ROTATORIA FROM LAKE MICHIGAN, ROUND LAKE, AND PINE LAKE.

This list includes limnetic, littoral and bottom species from these three lakes and from the channels connecting them. The three lakes are

included in one list on account of their open communication with each other and their similar characteristics; differences will be discussed in the notes at the end. The list does not include forms found in the shallow pools on the shores of Pine Lake, unconnected or only slightly connected with the main waters. These show a different character and are given in a separate list.

In order to show any differences in the fauna of the three lakes included in this one list, a letter is added in parenthesis, indicating in which lake or lakes the form was found. *M.* signifies Lake Michigan; *R.* signifies Round Lake; *P.* Pine Lake, and *C.* the natural channel connecting Round and Pine lakes. (See Pl. IV.)

The figures in parenthesis after the names of certain species refer to the systematic and faunistic notes at the end of the paper.

Rotatoria from Lake Michigan, Round Lake, Pine Lake, and the Channel Connecting Round Lake and Pine Lake.

Floscularia mutabilis Bolton. (M. R. P.)
Floscularia pelagica Rousselet. (M. R. P.)
Conochilus unicornis Rousselet. (M. R.)
Philodina roseola Ehrbg. (C.)
Philodina megalotrocha Ehrbg. (P. C.)
Philodina macrostyla Ehrbg. (M.)
Rotifer vulgaris Schrank. (P. C.)
Rotifer elongatus Weber. (M.)
Callidina musculosa Milne. (M.)
Asplanchna priodonta Gosse. (M. R. P. C.)
Asplanchna Herrickii de Guerne. (M. R. P.)
Asplanchnopus myrmeleo Ehrbg. (P.)
Ascomorpha ecaudis Perty. (M. R. P.)
Anapus ovalis Bergendal. (M. R. P.)
Synchæta stylata Wierz. (M. R. P.)
Polyarthra platyptera Ehrbg. (M. R. P.)
Notops pygmæus Calman. (M. R. P.)
Plœsoma lynceus Ehrbg. (M. R. P.)
Plœsoma Hudsoni Imhof. (M. R.)
Taphrocampa annulosa Gosse. (C.)
Notommata lacinulata Ehrbg. (R. C.)
Notommata monopus Jennings. (M. R. P.)
Copeus labiatus Gosse. (P.)
Proales laurentinus Jennings. (C.) (Note 2.)
Furcularia forificula Ehrbg. (P. C.)
Furcularia longiseta Ehrbg. (P. C.)
Triophthalmus dorsualis Ehrbg. (R. P.)
Eosphora aurita Ehrbg. (R.)
Diglena grandis Ehrbg, (C.)
Diglena forcipata Ehrbg. (C.)
Diglena catellina Ehrbg. (R. C.)
Mastigocerca carinata Ehrbg. (M. P.)
Mastigocerca bicornis Ehrbg. (M. R. P.)
Rattulus sulcatus Jennings. (C.)
Cœlopus porcellus Gosse. (C.)
Cœlopus tenuior Gosse. (C.)
Dinocharis pocillum Ehrbg. (R.)
Dinocharis tetractis Ehrbg. (M. C.)
Polychætus subquadratus Perty. (C.)
Polychætus Collinsii Gosse. (C.)
Scaridium longicaudatum Ehrbg. (P. C.)
Diaschiza semiaperta Gosse. (R. P. C.)
Euchlanis lyra Hudson. (R.)
Euchlanis deflexa Gosse. (C.)
Euchlanis oropha Gosse. (R. P. C.)
Cathypna luna Ehrbg. (C.)
Monostyla bulla Gosse. (C.)
Monostyla lunaris Ehrbg. (R. C.) (Note 6.)
Monostyla closterocerca Schmarda? (M. R. C.)
Metopidia lepadella Ehrbg. (C.)
Metopidia acuminata Ehrbg. (R.)
Metopidia Ehrenbergii Perty. (C.)
Brachionus Bakeri Ehrbg. (C.)
Anuræa aculeata Ehrbg. (M.)
Anuræa cochlearis Gosse. (M. R. P.)
Nothocla scapha Gosse. (M. R.)
Notholca foliacea Ehrbg. (R.)
Notholca longispina Kellicott. (M. R. P.)

Thus in these three connected lakes but fifty-eight species were found, as against one hundred and ten in Lake St. Clair during the preceding summer, though the investigation here was fully as thorough as that of Lake St. Clair. Twenty-four species were found in Lake Michigan, twenty-eight in Round Lake, twenty-five in Pine Lake, and twenty-nine in the shallow channel between Round Lake and Pine Lake. Lake Michigan has four species not found in the others, Round Lake five, Pine Lake two and the channel sixteen.

The great reduction in number comes especially in the littoral and bottom forms. The shores and bottom of Round Lake and Pine Lake were carefully examined, but the number of littoral or bottom forms is only

twenty-three. The small number is due to the general absence of vegetation. The few *Chara* beds of Pine Lake harbor very few rotifers. The channel connecting Round Lake and Pine Lake is shallow and contains considerable vegetation, so that a comparatively large number—twenty-nine—of distinctively littoral rotifers were found here.

In Lake Michigan almost no littoral or bottom forms were found. In a few cases vegetation from deep parts of the bottom was brought up by the dredges; in this eight bottom forms were found. These are *Philodina macrostyla* Ehrbg., *Rotifer elongatus* Weber, *Callidina musculosa* Milne, and *Dinocharis tetractius* Ehrbg., dredged from a depth of sixteen meters, and *Ascomorpha ecaudis* Perty, *Mastigocerca carinata* Ehrbg., *Mastigocerca bicornis* Erhbg., and *Monostyla closterocerca* Schmarda, depth not recorded.

The limnetic forms of the list are as follows:

Floscularia mutabilis Bolton.	Polyarthra platyptera Ehrbg.
Floscularia pelagica Rousselet.	Plœsoma lynceus Ehrbg.
Conochilus unicornis Rousselet.	Plœsoma Hudsoni Imhof.
Asplanchna priodonta Gosse.	Notops pygmæus Calman.
Asplanchna Herrickii de Guerne.	Notommata monopus Jennings.
Anapus ovalis Bergendal.	Anuræa cochlearis Gosse.
Synchæta stylata Wierz.	Notholca longispina Kellicott.

Mastigocerca bicornis Ehrbg. was taken several times in the towings, and as has been noted by other observers, seems to be a transitional form between limnetic and littoral Rotatoria. Isolated specimens of some few other rotifers—*Euchlanis oropha* Gosse, *Ascomorpha ecaudis* Perty, *Monostyla closterocerca* Schmarda, *Monostyla lunaris* Ehrbg., and *Notholca scapha* Gosse—were taken occasionally in the towings, but these were evidently wanderers from the bottom or shore.

The list then contains but fourteen limnetic Rotatoria, as against twenty-four from Lake St. Clair. With farther observation I am inclined to believe that a number of those in the Lake St. Clair list are due to the shallowness and rank vegetation of that lake. As such, and as therefore not entitled to be called genuine limnetic forms, I should consider *Apsilus lentiformis* Metsch., *Ascomorpha hyalina* Kellicott, and *Mastigocerca capucina* Wierz. and Zach.

As to the relative abundance of the different species, there is a general, though not exact, agreement with Lake St. Clair. Exact records of the presence of the forms in forty-nine towings taken at different times or places showed the relative frequency of the more common species as follows: *Anuræa cochlearis* Gosse occurred forty two times; *Notholca longispina* Kellicott, forty-one times; *Notops pygmæus* Calman, thirty-eight times. These three commonest species were followed at some distance by *Synchæta stylata* Wierz., twenty-eight times; *Plœsoma lynceus* Ehrbg., twenty-six times; *Polyarthra platyptera* Ehrbg., twenty-four times; *Asplanchna priodonta* Gosse, twenty-two times; *Floscularia mutabilis* Bolton, twenty-one times; *Conochilus unicornis* Rousselet, twenty-one times, and *Notommata monopus* Jennings, seventeen times. The others occurred in less than one-third the whole number of towings. As noted below, in the latter part of the summer *Asplanchna Herrickii* de Guerne became very abundant, forming by far the largest number of individuals in the towings during the last weeks of August.

The limnetic rotifers were considerably less abundant in Pine Lake than in the other two lakes. Thus the average number of species occurring in

the surface towings from Lake Michigan and from Round Lake was between nine and ten while from Pine Lake the average was but five and a half. In the bottom towings the average for Lake Michigan and Round Lake was five and a half, while for Pine Lake it was four and a half. Some species were not found at all in Pine Lake; this is true of *Conochilus unicornis* Rousselet, which was very common in the other two lakes; also of *Plœsoma Hudsoni* Imh. *Floscularia pelagica* Rousselet occurred but once from Pine Lake; *Plœsoma lynceus* Ehrbg., twice, *Synchæta stylata* Wierz. (very abundant in the other lakes), three times.

During the daylight the limnetic Rotifera are found in much greater numbers near the surface than near the bottom, reversing the condition commonly observed for the Crustacea. This fact is brought out distinctly in the record of towings. In eighteen recorded surface towings from Lake Michigan and Round Lake, taken on different days, the average number of species present was between nine and ten, and the number of individuals of many of these was very great. In twenty recorded towings from near the bottom of the same lakes, the average number of species found was between five and six, and generally but scattered individuals of each species were found—such as might have been caught in pulling the net to the surface. The difference in Pine Lake is not so considerable, since the number of species found there is very small, either at surface or bottom.

At night the distribution seems not to be materially changed. The immense numbers of Crustacea then present near the surface obscure the Rotifera; but no greater number of rotifers was found near the bottom, in the few towings made at night than in the daytime.

My observations tend most distinctly to show that there is great variation in the numbers of rotifers present in any one region within short periods of time; also that there is great variation in the numbers taken in different regions at about the same time. Certain forms seem fairly constant as to their presence in the towings, from the records given above, but these in some of the towings were present in immense numbers, while in other cases only scattered individuals were found. Other species were at one time present in large numbers, at other times entirely lacking, and this within short periods. This fact of great variations in the number and presence of rotifers is so apparent from the towing records that it is difficult to select any special examples. I will record one striking case of variation within twenty-four hours.

Aug. 22, at 2.30 p. m., I towed along the pier projecting into Lake Michigan from the entrance to the harbor of Charlevoix. The towings were made the full length of the pier four times. The material thus obtained contained immense quantities of *Asplanchna Herrickii* de Guerne. Careful examination of the preserved material led to the estimate that about one-fourth of the entire catch consisted of this form.

The next day at 10:30 a. m., I repeated the towings in the same place and with a similar net. The material collected was found to contain very few *Asplanchnas*. Thinking this might be due to some difference in the two nets, I took the same net used the day before, and at the same time of day, 2:30 p. m., I towed along the pier in exactly the same place and in the same way I had done the previous day. Towings were obtained in quantity similar to those of the day before, but they contained almost no specimens of *Asplanchna Herrickii;* after long examination I succeeded in finding a single specimen.

The two days were similar, both bright, with a slight wind, a little stronger on the second day. The direction of the slight current into the harbor was the same both days.

As to variations with the season, only one marked case came under my observation. In June and July, *Asplanchna priodonta* Gosse was one of the commonest limnetic rotifers, while *Asplanchna Herrickii* de Guerne was scarcely ever observed. But in the early part of August the numbers of *Asplanchna Herrickii* greatly increased, so that for a few days about equal numbers of the two species were found. Then the numbers of *Asplanchna priodonta* began to decrease very rapidly while the numbers of the other species continued to increase. In the latter part of August *Asplanchna Herrickii* was by far the most abundant rotifer in the towings, while *Asplanchna priodonta* had almost disappeared.

2. LIST OF ROTATORIA FROM POOLS ON THE SANDY SHORE OF PINE LAKE.

The shore of Pine Lake is in certain parts low, flat and sandy, with numerous very shallow pools, containing a thick growth of the finer algæ, and sometimes of *Utricularia*. Some of these pools are formed by the spreading out of rivulets flowing into the lake; in this case they are generally connected with the lake itself by narrow, shallow streamlets running a short distance over the sand, and containing no vegetation. Other pools are not under ordinary circumstances connected with the lake at all, but lie at the same level as its waters, separated from it by strips of sandy shore. These pools show a fauna differing in character from anything found in the main body of the lake, and a list of the twenty-seven species found is therefore given separately. Eleven of these species were found also in the waters connected with the main body of the three lakes; the rest were not:

Rotatoria from the Pools on the Shore of Pine Lake.

Philodina megalotrocha Ehrbg.
Philodina macrostyla Ehrbg.
Rotifer vulgaris Ehrbg.
Rotifer tardus Ehrbg.
Rotifer trisecatus Weber.
Microcodides orbiculodiscus Thorpe.
Copeus labiatus Gosse.
Furcularia forficula Ehrbg.
Furcularia gracilis Ehrbg.
Furcularia longiseta Ehrbg.
Furcularia micropus Gosse.
Furcularia semisetifera Glasscott.
Mastigocerca bicornis Ehrbg.
Rattulus sulcatus Jennings. (Note 2.)
Dinocharis tetractis Ehrbg.
Polychætus Collinsii Gosse.
Scaridium longicaudatum Ehrbg.
Euchlanis deflexa Gosse.
Euchlanis triquetra Ehrbg.
Monostyla cornuta Ehrbg.
Monostyla bulla Gosse.
Monostyla closterocerca Schmarda (?).
Metopidia lepadella Ehrbg.
Metopidia Ehrenbergii Perty.
Pterodina patina Ehrbg.
Pterodina reflexa Gosse.
Noteus quadricornis Ehrbg.

3. LIST OF ROTATORIA FROM WEST TWIN LAKE.

West Twin Lake is a small inland lake lying at a distance of several miles from the other lakes examined, and connected with Pine Lake only by a small stream. It differs markedly in its main characteristics from the waters directly connected with Lake Michigan. The shores and bottom are of soft deep mud, and vegetation is abundant. Here the rotatorial fauna is much more like that of the shallow parts of Lake St. Clair than was found elsewhere in this region. From this lake the following species were identified.

Rotatoria from West Twin Lake.

Floscularia companulata Dobie.
Floscularia mutabilis Bolton.
Stephanoceros Eichhornii Ehrbg.
Oecistes mucicola Kellicott.
Lacinularia socialis Ehrbg.
Conochilus volvox Ehrbg.
Philodina macrostyla Ehrbg.
Microcodon clavus Ehrbg.
Asplanchnopus myrmeleo Ehrbg.
Ascomorpha hyalina Kellicott.
Anapus ovalis Bergendal.
Synchæta stylata Wierz. (Note 1.)
Polyarthra platyptera Ehrbg.
Notops pygmæus Calman.
Plœsoma lynceus Ehrbg.
Notommata lacinulata Ehrbg.
Notommata monopus Jennings.
Proales laurentinus Jennings. (Note 2.)
Furcularia longiseta Ehrbg.
Diglena grandis Ehrbg.
Mastigocerca bicristata Gosse. (Note 3.)
Mastigocerca capucina Wierz. u. Zach.
Mastigocerca lata Jennings.
Rattulus sulcatus Jennings. (Note 4.)
Dinocharis tetractis Ehrbg.
Euchlanis triquetra Ehrbg.
Euchlanis oropha Gosse.
Cathypna luna Ehrbg.
Distyla signifera n. sp. (Note 5.)
Monostyla bulla Gosse.
Monostyla quadridentata Ehrbg.
Metopidia Ehrenbergii Perty.
Pterodina patina Ehrbg.
Pterodina parva Ternetz.
Pterodina reflexa Gosse.
Brachionus Bakeri Ehrbg.
Brachionus militaris Ehrbg.
Anuræa cochlearis Gosse.

4. LIST OF SOME ROTATORIA IN MATERIAL BROUGHT FROM SUSAN LAKE.

Melicerta ringens Schrank.
Asplanchna Herrickii de Guerne.
Plœsoma lynceus Ehrbg.
Notommata monopus Jennings.
Brachionus militaris Ehrbg.

5. LIST OF ROTATORIA FROM SPHAGNUM SWAMPS NEAR PINE LAKE.

Near the shores of Pine Lake are a number of "tamarack swamps," formed by the spreading out of small streams before entering the lake. These are filled with *Sphagnum* and similar vegetable life, and covered with a dense growth of underbrush and trees, among which the tamarack is predominant. An examination of material brought from these shows that rotifers are not abundant; the forms found are mostly of the families everywhere characteristic of Sphagnum swamps—the *Philodinadæ Cathypnadæ*, and *Coluridæ*. A list of some forms identified is here given:

Rotatoria from Sphagnum Swamps near Pine Lake.

Philodina aculeata Ehrbg.
Callidina constricta Duj.
Callidina magna Plate.
Callidina papillosa Thompson.
Adineta vaga Davis.
Copeus pachyurus Gosse.
Distyla inermis Bryce.
Metopidia solidus Gosse.
Metopidia triptera Ehrbg.

6. LIST OF SPECIES NEW TO THE FAUNA OF MICHIGAN.

In the foregoing lists, containing in all ninety-four species, the following twenty species are recorded for the first time as occurring in Michigan, and so far as I am aware, in America:

Callidina constricta Duj.
Callidina magna Plate.
Callidina papillosa Thompson.
Callidina musculosa Milne.
Adineta vaga Davis.
Asplanchnopus myrmeleo Ehrbg.
Copeus pachyurus Gosse.
Furcularia micropus Gosse.
Furcularia semisetifera Glasscott.
Triophthalmus dorsualis Ehrbg.
Diglena catellina Ehrbg.
Mastigocerca bicristata Gosse.
Cœlopus tenuior Gosse.
Polychætus Collinsii Gosse.
Distyla signifera n. sp.
Distyla inermis Bryce.
Metopidia solidus Gosse.
Pterodina parva Ternetz.
Notholca scapha Gosse.
Notholca foliacea Ehrbg.

7. SYSTEMATIC AND FAUNISTIC NOTES ON CERTAIN SPECIES IN THE PRECEDING LISTS.

(1.) *Synchæta stylata* Wierz.

In my first report on the Rotatoria (Bulletin of the Michigan Fish Commission, No. 3, 1894), I noted the fact that one of the most abundant of the limnetic Rotatoria in Lake St. Clair was *Synchæta stylata* Wierz., while in Whitmore Lake, a small body of water unconnected with the great lakes, *Synchæta pectinata* Ehrbg. was found in equal numbers while *Synchæta stylata* was not present. In the summer of 1894 I hoped to make farther observations on this peculiar difference. In Lake Michigan, Round Lake, and Pine Lake, as was to be expected, only *Synchæta stylata* was found. It seemed possible that in the small inland lake known as West Twin Lake, only indirectly connected with the great lake system, *Synchæta pectinata* would again occur. But such was not the case; *Synchæta stylata* was found in numbers, but no other member of the genus occurred. At the present time, therefore *Synchæta pectinata* has been reported only from Whitmore Lake.

(2.) *Proales laurentinus* Jennings.

This is the form described in Bulletin of the Michigan Fish Commission, No. 3, 1894, as *Notops laurentinus*. The tendency has been in the past few years to consider the genus *Notops* as typically loricate, though belonging to an illoricate family. Of the species described in Hudson and Gosse's Monograph, one is loricate while the other two are not, and the other two genera of this family—*Hydatina* and *Rhinops*—are distinctly illoricate. But *Notops minor* Rousselet, (Journal of the Quekett Microscopical Club, 1892, Series 2, Vol. 4, p. 359), and *Notops pygmæus* Calman, (Annals of Scottish Natural History, Oct. 1892, p. 240), are loricate forms, and show the general tendency to consider this a loricate group. As my species, besides being illoricate, shows undoubted Notommatoid characteristics in other respects, as was noted in my description, it should probably be transferred to another genus. Mr. Charles Rousselet, of London, England has recently discovered on Hertford Heath a species very similar to this, but of a more slender form, showing still farther the relationship with the *Notommatadæ*. His species could not possibly be considered a *Notops*, and as the two undoubtedly belong together I have adopted the suggestion of Mr. Rousselet that both should be referred to the rather heterogeneous and ill defined genus *Proales*.

(3.) *Mastigocerca bicristata* Gosse.

This is not the form mentioned on page 19 of my report in Bulletin of the Michigan Fish Commission No. 3, 1894, but is evidently the real *Mastigocerca bicristata* of Gosse, while the form there mentioned is a new species. It agrees with *Mastigocerca bicristata* Gosse in having two crests, but differs markedly in other respects. Only a few specimens of the real *Mastigocerca bicristata* were found amid *Utricularia* from West Twin Lake. The other two-crested species was very abundant, especially in Round Lake and in the channel between Round Lake and Pine Lake. It is hoped some time in the future to publish careful comparative descriptions of the two forms; at present my notes and figures are not complete.

(4.) *Rattulus sulcatus* Jennings.

This form was described and figured by Bilfinger, in a paper which came just too late to be mentioned in my previous report (l. c.), as *Cœlopus brachiurus* Gosse (?). (Bilfinger *Zur Rotatorienfauna Württembergs*,

Zweiter Beitrag, Jahreshefte des Vereins für vaterl. Naturkunde in Württemberg, 1894.) As Bilfinger states, the animal is unquestionably a *Rattulus* and not a *Cœlopus*. I have seen the two equal toes widely separated, then closed together again. Furthermore the toes are here very short (0.022 mm.) both relatively and absolutely, forming only about one-seventh of the entire length of the animal (0.144 mm.). I give Bilfinger's measurements, as they agree almost exactly with my own. But in *Cœlopus brachiurus* as described and figured by Gosse, the toes are both relatively and absolutely much longer ($\frac{1}{580}$ inch = .043 mm.), forming about one-fourth of the entire length of the animal. Mr. Charles Rousselet has been so good as to send me some farther notes and figure of *Cœlopus brachiurus* Gosse, as found in England, and from these the distinctness of the two forms seem still more clear. *Cœlopus brachiurus* swims commonly with the toes held straight out behind, according to Mr. Rousselet, whereas in the many living specimens of this *Rattulus* which I have seen, the toes are always retracted, as shown in my own figures and that of Bilfinger. Bilfinger states also that in all specimens seen by him the toes were retracted. In *Cœlopus brachiurus*, even when the toes are "thrust up under the belly," as figured by Gosse in the monograph, they are not held at all in the same position as in *Rattulus sulcatus*, being turned points forward instead of being retracted into the lorica in their natural position.

The following then are the points of difference:

Cœlopus brachiurus Gosse.	*Rattulus sulcatus* Jennings.
Toes of the *Cœlopus* type (?).	Toes equal and side by side (*Rattulus* type).
Length of toes, $\frac{1}{580}$ inch=.043 mm.	Length of toes, .022 mm.
Total length, $\frac{1}{135}$ inch=.185 mm.	Total length, .144 mm.
Toes nearly ¼ of entire length.	Toes about $\frac{1}{7}$ of entire length.
Toes held straight out behind or curved, points forward.	Toes retracted within the lorica.

It seems to me beyond question that the two forms are distinct.

Mr. Rousselet suggested the possibility of the identity of this form with *Cœlopus porcellus* Gosse, and sent me mounted specimens of that form for comparison. The distinction is at once evident on comparing the two animals; moreover, *Cœlopus porcellus* is common in Michigan. I was acquainted with it before I saw this Rattulus.

Rattulus sulcatus it seems to me then is certainly a species distinct from any hitherto described.

(5.) *Distyla signifera* n. sp.

Lorica of the flattened truncate elliptical form typical of the genus: the whole animal in general form much like the *Distyla inermis* of Bryce (Science Gossip, Dec., 1892), though perhaps a little broader. But the *lorica is marked both dorsally and ventrally by crescentic elevations*, arranged in somewhat regular patterns. On the ventral surface these are mostly in longitudinal rows, while on the dorsal surface the pattern is considerably more complicated and at the same time less regular. The two figures, from camera drawings, render a minute description of the arrangement of these elevations superfluous. The dorsal view shows not only the arrangement but also, so far as possible, the size and form of each of the markings; in the ventral view the arrangement is accurate, but each elevation was not outlined separately with the camera. The toes are rod-like, tapering near the distal end on the *outer* side, so as to form an inner

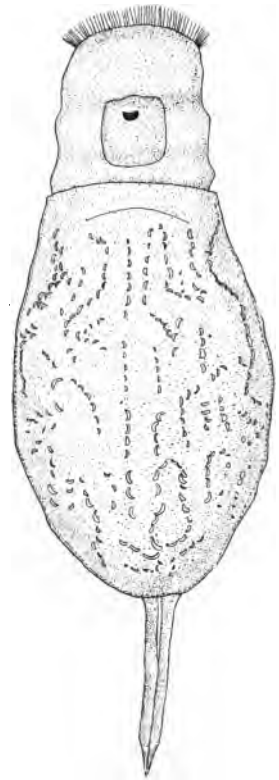

FIG. 1.

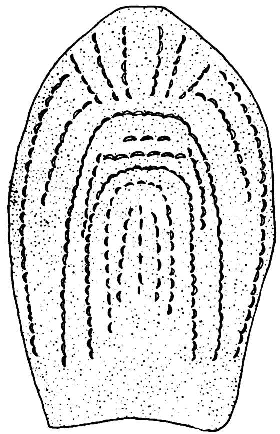

FIG. 2.

point—so that when the two toes are placed side by side only one point is formed. The internal anatomy offers nothing of interest.

All distinctive characters of the animal are better indicated by the figures than would be possible by an extended description.

Length, about .22 mm.

In Utricularia from West Twin Lake; not common.

Figure 1.—Dorsal view of the entire animal.

Figure 2.—Ventral view of the lorica.

(6.) *Monostyla lunaris* Ehrbg.

This common form agrees with descriptions and figures of *Monostyla lunaris* Ehrbg., except that the toe is *not protruded between two spines*, but the foot passes without break into the toe. The foot is *unjointed*, so that this is not the *Monostyla Quennerstedtii* of Bergendal. I have not considered this variation to be of sufficient importance to separate my form from the common one.

APPENDIX IV.

PRELIMINARY REPORT ON COLLECTIONS OF TURBELLARIA FROM LAKE ST. CLAIR AND CHARLEVOIX, MICHIGAN.[1]

BY W. McM. WOODWORTH, INSTRUCTOR IN MICROSCOPICAL ANATOMY, AND MUSEUM ASSISTANT IN CHARGE OF VERMES, HARVARD UNIVERSITY.

A more detailed report with figures will appear in the Bulletin of the Museum of Comparative Zoölogy.

The collections, though small, contribute three new species to the Turbellarian fauna of the United States, two of which have never before been described. In the absence of any data regarding the color and shape of the living animals, the descriptions are necessarily based upon the appearances of the alcoholic material.

Planaria simplex sp. nov.

One Specimen. "Dredge Aug. 11, 1894, off N. Y. Point, Lake Michigan." Length 4 mm., greatest breadth 1.8 mm. General shape ovate. Broadest at $\frac{1}{5}$ the total length from the anterior end, tapering from here to rounded posterior extremity. Anterior end rounded, set off from rest of body by slight lateral indentations at the level of the eyes, i. e., about $\frac{1}{10}$ the total length from anterior end. Broadest diameter $\frac{1}{5}$ the distance from anterior end. No cephalic appendages. Mouth $\frac{1}{3}$ total length from posterior end. Eye spots elongated, crescentic, facing outward and forward at an angle of 45° to the chief axis of the worm. Intestine of the simple triclad type. No signs of sexual organs. Immature. Pigment, located in spots of nearly uniform size, distributed uniformly over all parts of the body; no clear areas at sides of head nor surrounding the eyes. Color of alcoholic specimen ochre yellow.

Planaria maculata Leidy.

One specimen from New Baltimore, Lake St. Clair, Aug. 20, 1893. Seven specimens "on leaves of Nymphea, Twin lakes, Charlevoix, Aug. 6, 1894." Four specimens from "Utricularia-washings, West Twin Lake, Charlevoix, Aug. 13, 1894."

[1] Contributions from the Zoölogical Laboratory of the Museum of Comparative Zoölogy, E. L. Mark, director, No. LXIII.

* **Procotyla fluviatilis** Leidy.

"Round Lake July 9, 1894." Probably the above species. Catalogued as "white planarian." No other data.

Mesostoma Wardii sp. nov.

Nine specimens: "Turbellaria [from] algæ, Aug. 20, 1893, New Baltimore," Lake St. Clair. Length 2–3 mm., greatest breadth 1–1.4 mm. Very thin and flat. Anterior end tapering, rounded, marked off from body by a slight constriction. Posterior end tapering sharply and terminating in an acute caudal process. Pharynx large, prominent, in middle third of body. Specimens mostly immature; nothing definite could be determined regarding the sexual organs. Color of alcoholic material yellowish; very translucent.

Mesostoma viridatum M. Sch.

Seven specimens from "Utricularia-washings, West Twin Lake, Charlevoix, Aug. 13, 1894." A cosmopolitan form, but new to the United States.

* **Mesostoma viviparum** Silliman.

"Old channel, Round Lake, Charlevoix, on algæ, July 13, 1894."

* **Vortex armiger** O. Schm.

New Baltimore, Lake St. Clair, Aug. 6, 1893.

* **Vortex** sp.?

"Round Lake, Charlevoix, dredgings from old channel July 20, 1894. Length 0.96 mm., breadth 0.24–0.32 mm. Anterior end truncated posterior end pointed. Pharynx dolioform, in anterior $\frac{1}{3}$ of body, traversed by two prominent, lateral, nearly longitudinal bands of light chocolate color. Zoöchlorellæ in central part of body."

Microstoma lineare Oers.

One broken stock from "Utricularia-washings, West Twin Lake, Charlevoix, Aug. 13, 1894."

*"Old channel, Round Lake, Charlevoix, July 13, 1894, in chains of 2 to 4."

* **Microstoma variabile** Leidy.

"Algæ culture, shore, Charlevoix, July 24, 1894. One specimen: chain of four individuals."

Microstoma caudatum Leidy.

Two specimens from "Utricularia-washings, West Twin Lake, Charlevoix, Aug. 13, 1894." Both stocks consisting of two individuals.

Museum of Comparative Zoölogy,
Cambridge, Mass., Jan. 31, 1896.

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* The species marked with an asterisk were not sent to me. The accounts given here are from notes and drawings by Prof. H. B. Ward.

APPENDIX V.

REPORT UPON THE MOLLUSCA COLLECTED IN THE VICINITY OF CHARLEVOIX, MICHIGAN, IN THE SUMMER OF 1894.

BY BRYANT WALKER, DETROIT, MICH.

The molluscan fauna of Charlevoix, is that common to the northern portion of the lower peninsula, and seems to possess but little that is purely local in its nature. As a whole, however, it is distinctly northern in its character, as compared with that of the southern part of the state. In the terrestrial species this is shown in the occurrence of *Vitrina* and numerous species of Zonitidæ and Endodontidæ, to the almost entire exclusion of the larger species of Helicidæ, which abound further south. While in the aquatic forms, the Limnæidæ, Physidæ, and Corbiculidæ, all of which are peculiarly northern in their distribution, form nearly three-fourths of the entire number of species.

The number of species of terrestrial mollusca collected was not as great as might reasonably have been expected. This was probably in part due to the sandy nature of the soil, which prevails all along the eastern shore of Lake Michigan, and partly to the excessive drought which then prevailed. Of the thirty-one species collected, two—*Pyramidula asteriscus* Mse., and *Strobilops virgo* Pils.—are interesting additions to the fauna of the state.

The number of fluviatile species collected was sixty-four, of these thirty-seven were univalves and twenty-seven were bivalves.

The following is a summary of the families represented:

Pulmonata	Limnæidæ	22	
	Physidæ	4	
			26
Prosobranchiata	Valvatidæ	2	
	Viviparidæ	3	
	Rissoidæ	4	
	Pleuroceridæ	2	
			11
Pelecypoda	Unionidæ	9	
	Corbiculidæ	18	
			27

The most striking feature of this fauna is the large number of species belonging to the Corbiculidæ. Of the nineteen species recognized, no less than ten are new to the fauna of the State, and of these, one (*Pisidium milium* Held.) is a European species not before found in this country, and seven (*Sphœrium* 1, *Pisidium* 6) are probably new to science.

Other interesting discoveries were a small and very fragile deep-water form of *Limnœa stagnalis* L. and very small globose *Limnœa*, which may prove to be a new form, at High Island Harbor in the Beaver islands; a new fossil *Limnœa* from the marl deposits in Pine Lake at Charlevoix, and the recently described *Planorbis bicarinatus Aroostookensis* Pils. and *P. exacutus rubellus* Sterki from small ponds in the same vicinity.

The fauna of Lake Michigan does not seem to differ materially from that of the neighboring inland lakes. The apparent scarcity of the larger bivalves (*Unio, Anodonta* and *Margaritina*) shown in the present collection may possibly be explained by the unfavorable conditions which prevail in the immediate neighborhood of Charlevoix, owing to the exposed coast and rocky bottom in that vicinity. Further and more extended observations will be necessary before such a deduction can be made with any degree of certainty.

This fact, if it be one, does not, however, play any considerable part in the economic features of the fauna which more particularly concern the special line of investigation carried on by the Commission.

It is not probable, owing to their large size and heavy shells, that the Unionidæ afford any considerable amount of fish food. In the earlier stages of development, while yet small they no doubt are eaten to some extent.

There is no question, however, but that the smaller species which are to be found in great quantities in suitable localities, constitute an important item in the food supply of those species of lake fish, such as the whitefish, sturgeon, etc., which are bottom feeders. The forms thus utilized, would include among the univalves most of the species belonging to the following genera: *Limnœa, Physa, Planorbis, Segmentina, Valvata, Amnicola* and *Bythinella* and among the bivalves, the numerous species of *Sphœrium* and *Pisidium.*

The following genera were found in the stomachs of whitefish collected this last season:

Amnicola, Valvata, Sphœrium, Pisidium, Limnœa, Physa, Planorbis.

The great abundance of these small mollusks under favorable conditions was well shown at High Island, where a single haul of the trawl over a thick growth of *Chara* brought to surface several hundred specimens of twenty-six species belonging to the following genera:

Limnœa	5
Planorbis	3
Physa	1
Valvata	2
Amnicola	3
Bythinella	1
Pisidium	11

Not only are these forms exceedingly abundant, but their bathymetric range is also very considerable. Thus *Limnœa, Planorbis, Valvata, Amnicola, Sphœrium* and *Pisidium* were found living at a depth of twenty-

five metres. Although, in the few instances in which the dredge was lowered to a greater depth, no mollusca were obtained, this result can scarcely be considered as determinative in this particular. It seems probable, however, that the *Pisidia* range to a much greater depth than the other genera.

(See Rep. U. S. Fish Com. 1872-3, page 707).

As in other forms of animals, the abundance of molluscan life is dependent upon a favorable environment and ample supply of food. All of the univalves species found in the great lakes are vegetable feeders, while the bivalves live upon the minute organisms (algæ) which they find floating in the water. An abundant vegetation therefore is a prime requisite for any extensive development of a molluscan fauna.

This interdependence of the various forms of life was very strikingly illustrated in the fauna of the various inland lakes in the vicinity of Charlevoix. Thus in Pine Lake where, owing to the character of the bottom which is almost wholly composed of a fine disintegrated marl, except in places where a thin coating of sand has been washed in from the shore, plant life is very meagre and stunted in its growth, there was a marked scarcity in the mollusca, not only in the number of species, but in their individual abundance. While in other lakes when the conditions were favorable for a luxuriant vegetation, there was a corresponding increase in the higher forms of life.

The following is a complete list of the species collected:

	Land.	Lake Michigan.	Inland waters.
Limax campestris Binn.	X		
Vitrina limpida Gld.	X		
Gastrodonta nitidus Mull.	X		
Vitrea arboreus Say.	X		
radiatulus Alder	X		
indentatus Say.	X		
Binneyanus Mse.	X		
ferreus Mse.	X		
exiguus Stimp.	X		
Conulus fulvus Dr.	X		
Tebennophorus Carolinensis Bosc.	X		
Pyramidula alternata Say.	X		
alternata alba.	X		
striatella Anth.	X		
asteriscus Mse.	X		
lineata Say.	X		
Polygyra albolabris Say.	X		
Sayi Binn.	X		
monodon Rack.	X		
Strobilops labyrinthica Say.	X		
virgo Pils.	X		
Acanthinula harpa Say.	X		
Pupa contracta Say.	X		
Vertigo ovata Say.	X		
Bollesiana Mse.	X		
ventricosa elatior Sterki	X		
pentodon Say.	X		
Ferussacia subcylindrica L.	X		
Succinea avara Say	X		
obliqua Say.	X		
ovalis Gld. var.	X		
Carychium exiguum Say.	X		
Limnæa stagnalis L.			X
stagnalis L. var.		X	
ampla Migh.			X
emarginata Say.		X	
catascopium Say.		X	X
reflexa Say.			X
lanceata Gld.?		X	

	Land.	Lake Michigan.	Inland waters.
Limnœa pallida Ads.? (fossil)			X
galbana Say. (fossil)			X
desidiosa Say		X	X
humilis Say			X
sp.		X	
sp. (fossil)			X
Physa ancillaria Say.		X	X
gyrina Say.		X	X
heterostropha Say.			X
integra Hald.		X	X
Planorbis trivolvis Say.			X
bicarinatus Say.		X	X
bicarinatus Aroostookensis Pils.			X
campanulatus Say.			X
multivolvis Case.			X
exacutus Say.		X	
exacutus rubellus Sterki.			X
albus Mull.			X
parvus Say.		X	X
deflectus Say.			X
Segmentina armigera Say.			X
Ancylus parallelus Hald.			X
Valvata tricarinata Say.		X	X
tricarinata bicarinata Lea.		X	
sincera Say.		X	
Campeloma decisa Say.		X	X
integra Say.			X
Milesii Lea.			X
Amnicola limosa Say.		X	X
lustrica Pils.		X	X
grana Say.		X	
porata		X	X
Bythinella obtusa Lea.		X	
Pleurocera subulare Lea.			X
Goniobasis livescens Mke.		X	X
Unio luteolus Lam.			X
borealis Gray.			X
Margaritina rugosa Bar.			X
Anodonta edentula Say.			X
fragilis Lam.			X
Footiana Lea.		X	
Marryatana Lea.			X.
Ferussaciana Lea.		X	
subcylindracea Lea.		X	X
Sphærium simile Say.		X	X
striatinum Lam.		X	X
rhomboideum Say.			X
rosaceum Pme.			X
sp.		X	
Pisidium Idahoense Roper.		X	
variabile Pme.		X	X
abditum Hald.		X	X
compressum Pme.		X	X
ventricosum Pme.		X	X
punctatum Sterki.		X	
sp.		X	X
sp.		X	X
sp.		X	X
trapezoideum Sterki, mss.		X	X
sp.		X	
sp.		X	
milium Held.			X

ERRATA.

Page 3, line 13, for " Reighard, 95," read " Reighard, 94".
Page 8, footnote, line 2, for " p. 250 " read " p. 259".
Page 11, second line from bottom, for " p. —" read " p. 72".
Page 12, line 24, for " p. —" read " p. 76".
Page 12, line 28, for " Ryder (81)" read " Ryder (84)".
Page 16, line 7, after " species " insert " of insects".
Page 17, sixth line from bottom, for " Reighard (95)" read " Reighard (94)".
Page 19, line 15, for " Forbes (82)" read " Forbes (83)".
Page 21, line 11 of table, for " ***lustuca*** **" read "** ***lustrica*** **".**
Page 21, line 15 of table, for " Lan." read " Lam."
Page 27, line 26, for " depedent " read " dependent ".
Page 28, second footnote in third and in last lines, for " ***Melonia*** **" read "** ***Melosira*** **".**
Page 36, last line above table omit the word " total ".
Page 37, line 20, for " afford " read " affords ".
Page 38, second table in first line, for " 10.7 " read "10.0," and for " 3.6 " read " 4. 3 ".
Page 38, second table in last line, for " 19.5118 " read " 19.4937"
Page 38, last line, for " 3.5 per cent " read " 4 per cent".
Page 43, last table in last column, for " 3.98 " read " 3.97".
Page 45, line 24, for " agreed " read " agrees".
Page 55, line 8, for " Clain " read " Clair".
Page 55, line 34, for " Reighard (93)," read "(94)".

CONTENTS.

PLATE I.

TABULAR VIEW OF BOTTOM HAULS WITH VERTICAL NET.

A, IN LAKE MICHIGAN.

B, IN ROUND AND PINE LAKES.

Vertical lines indicate stations, each of which is designated by a Roman numeral at the upper end.

Horizontal lines denote distance or amount as shown at the margin.

D........D. Indicates depth of various stations.

T........T. Shows total volume of plankton in bottom hauls with vertical net.

R........R. Shows the estimated volume of plankton per cubic meter of water in the same hauls.

? Denotes a doubtful observation.

For further details see text.

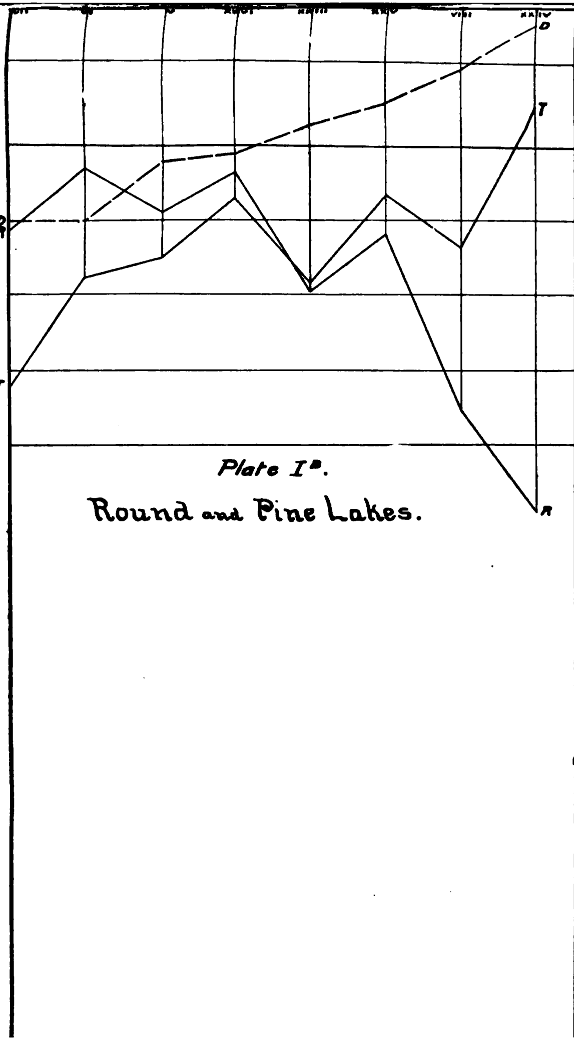


Plate I^B.

Round and Pine Lakes.

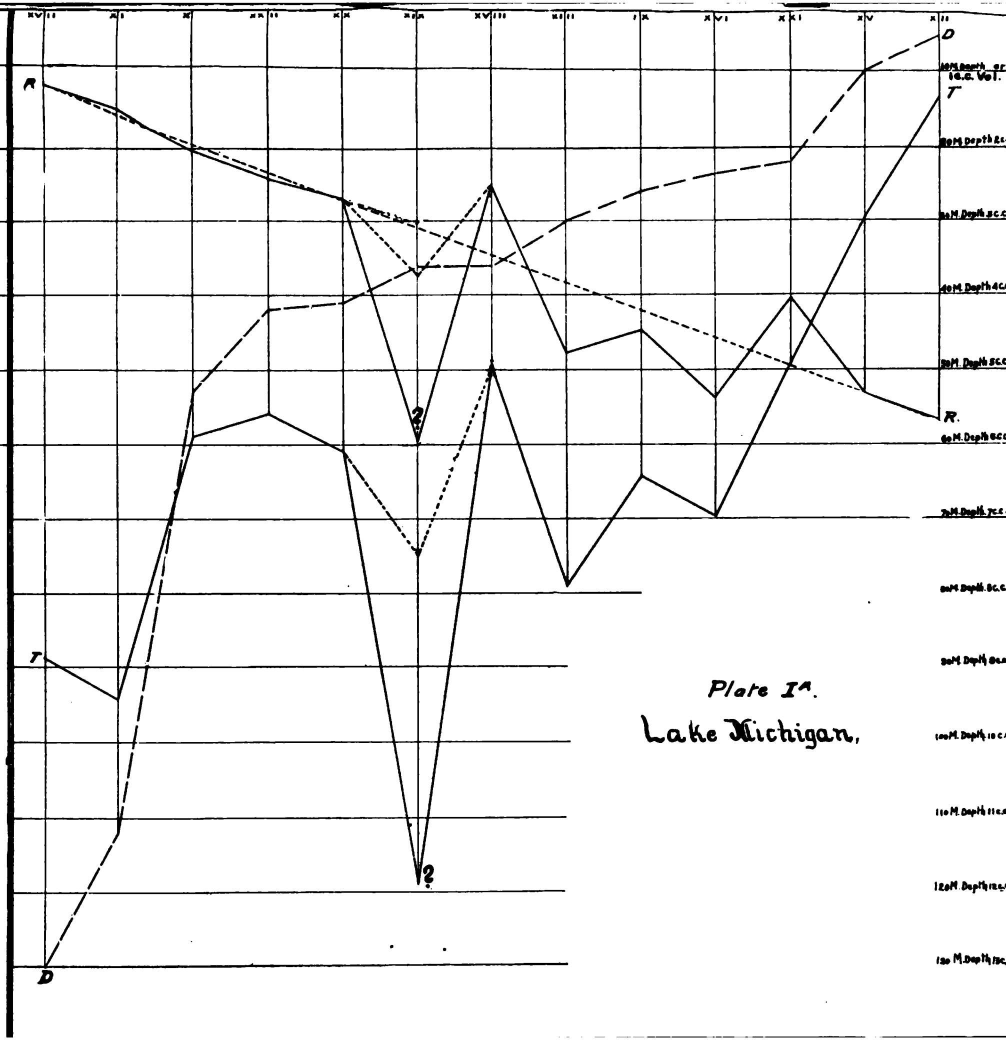


Plate I^A.

Lake Michigan,

PLATE II.

TABULAR VIEW OF STRATAL HAULS WITH VERTICAL NET.

A, IN LAKE MICHIGAN.

B, IN ROUND AND PINE LAKES.

Vertical lines indicate stations, and horizontal lines amount of plankton obtained

D--------D. Indicates the depth of various stations.

S--------S. Shows the amount of plankton per cubic meter of water in hauls from 2m. to surface.

2–5m., the same in hauls from 5m.–2m.

5–10m., " " " " " 10m.–5m.

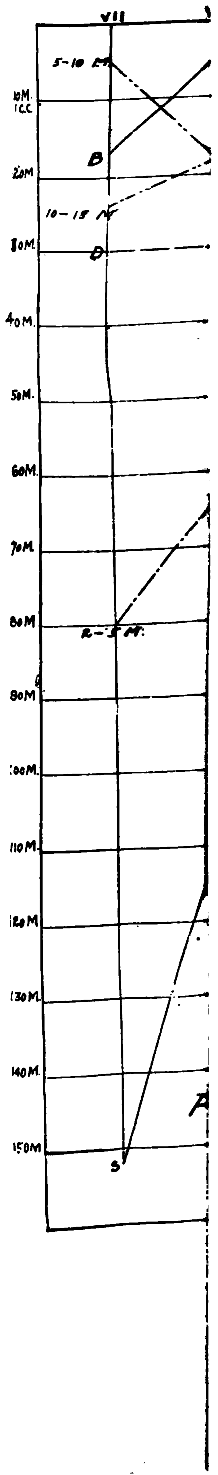
10–25m., " " " " " 25m.–10m.

25–50m., " " " " " 25m.–50m.

50m.–bottom, the same in hauls from bottom to 50m.

? Denotes a doubtful record or observation.

Further details in text.



VII
5-10 M.
10M.
I.C.C.
B
20M
10-15 M
30M
D
40M.
50M.
60M.
70M.
80M
R-5 M.
90M
100M.
110M.
120M
130M.
140M.
150M
S

PLATE III.

TABULAR VIEW OF PLANKTON HAULS IN LAKE ST. CLAIR. THESE WERE PLOTTED FROM RESULTS GIVEN BY REIGHARD, 94, p. 35.

Stations are indicated by vertical lines; distances or amounts by horizontal lines.

D--------D. Indicates the depth of the various stations.

T--------T. Shows the total amount of plankton obtained in bottom hauls.

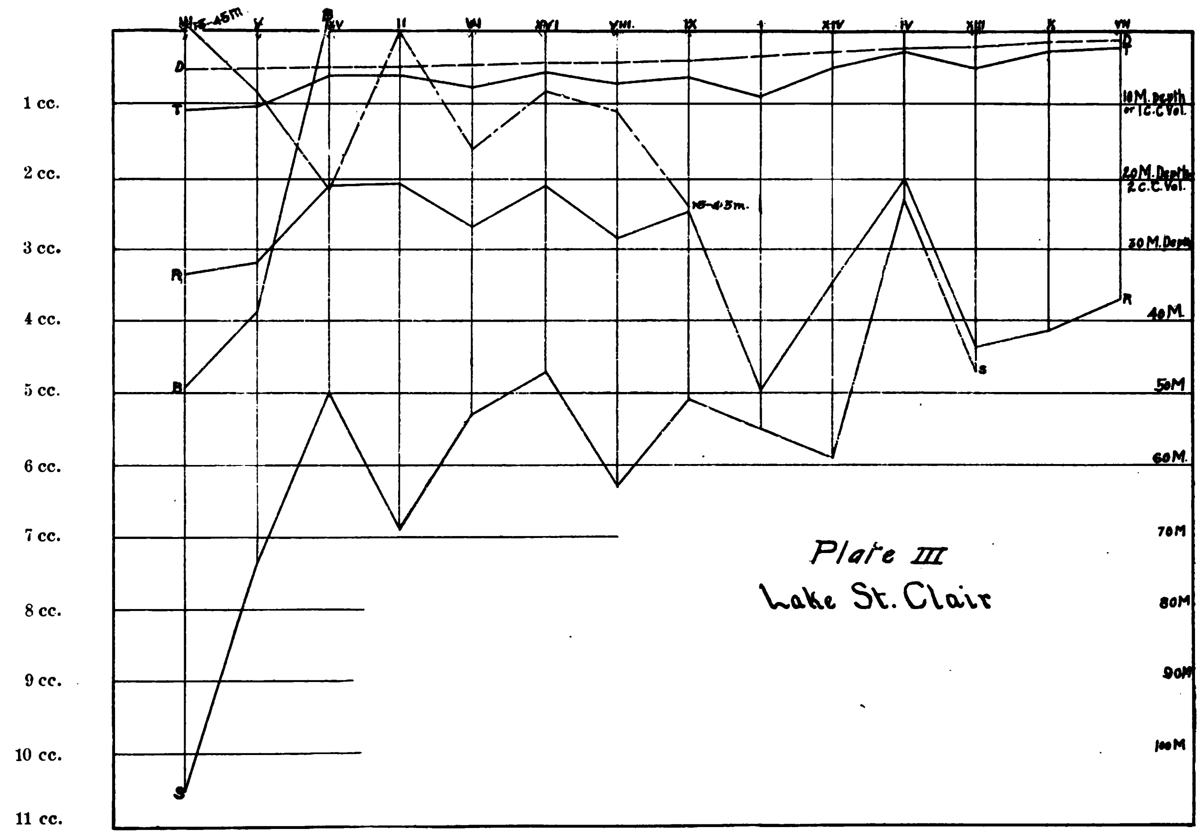
R--------R. The amount of plankton per cubic meter of water for the same hauls.

S--------S. The amount of plankton per cubic meter of water contained in the surface 1.5m.

1.5–4.5m. The amount of plankton per cubic meter of water in the stratum 4.5m. to 1.5m., or bottom to 1.5m. if shallower.

B--------B. The amount of plankton per cubic meter of water in the stratum from bottom to 4.5m.

For discussion and explanation see text.



1 cc.
2 cc.
3 cc.
4 cc.
5 cc.
6 cc.
7 cc.
8 cc.
9 cc.
10 cc.
11 cc.
10 M. Depth or 1 C.C. Vol.
20 M. Depth 2 C.C. Vol.
30 M. Depth
40 M.
50 M
60 M.
70 M
80 M
90 M
100 M
D
T
R
B
S
Plate III
Lake St. Clair

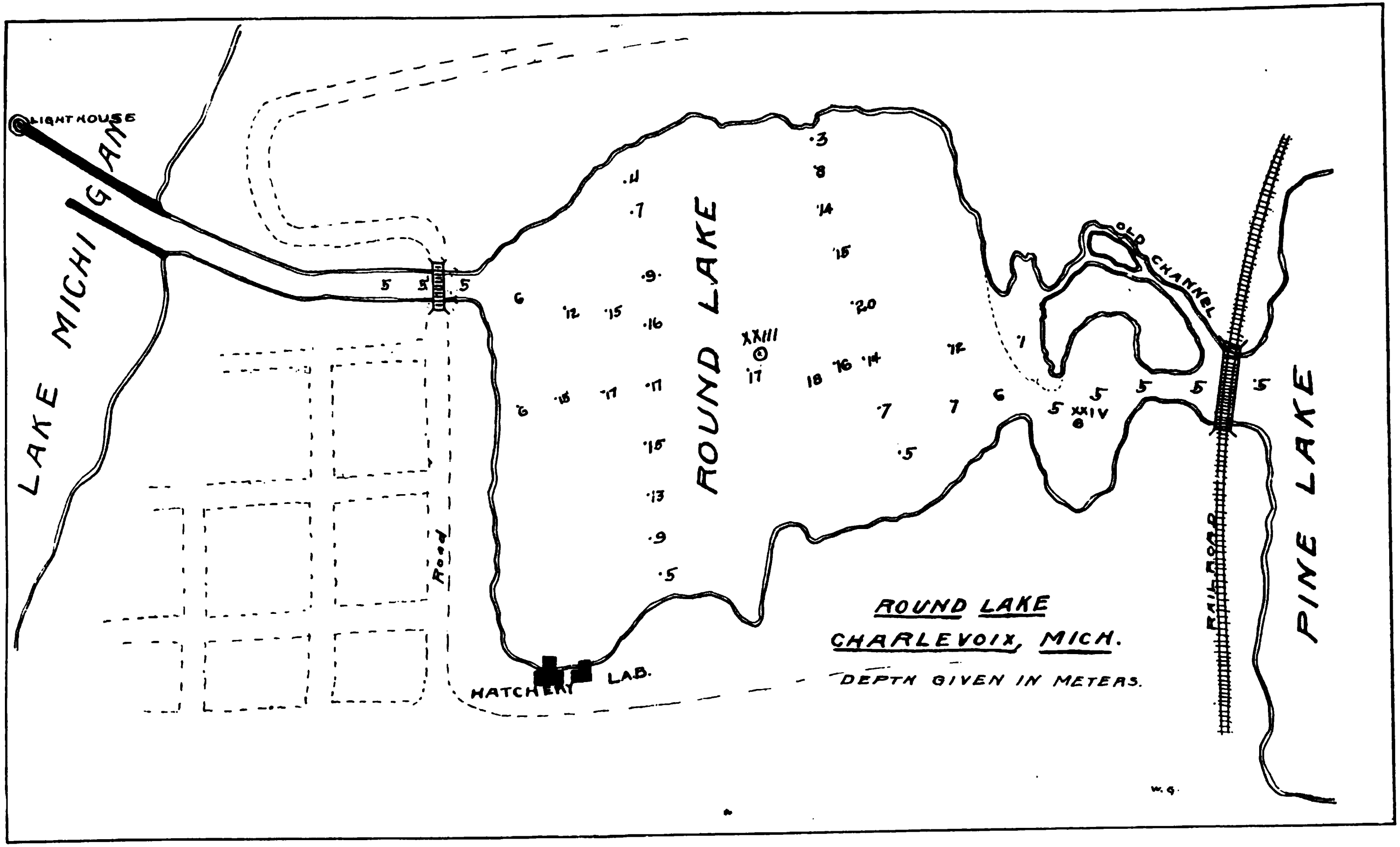

LIGHTHOUSE
LAKE MICHIGAN
ROUND LAKE
OLD CHANNEL
RAILROAD
PINE LAKE
XXIII
XXIV
Road
HATCHERY
LAB.
ROUND LAKE
CHARLEVOIX, MICH.
DEPTH GIVEN IN METERS.

PLATE IV.

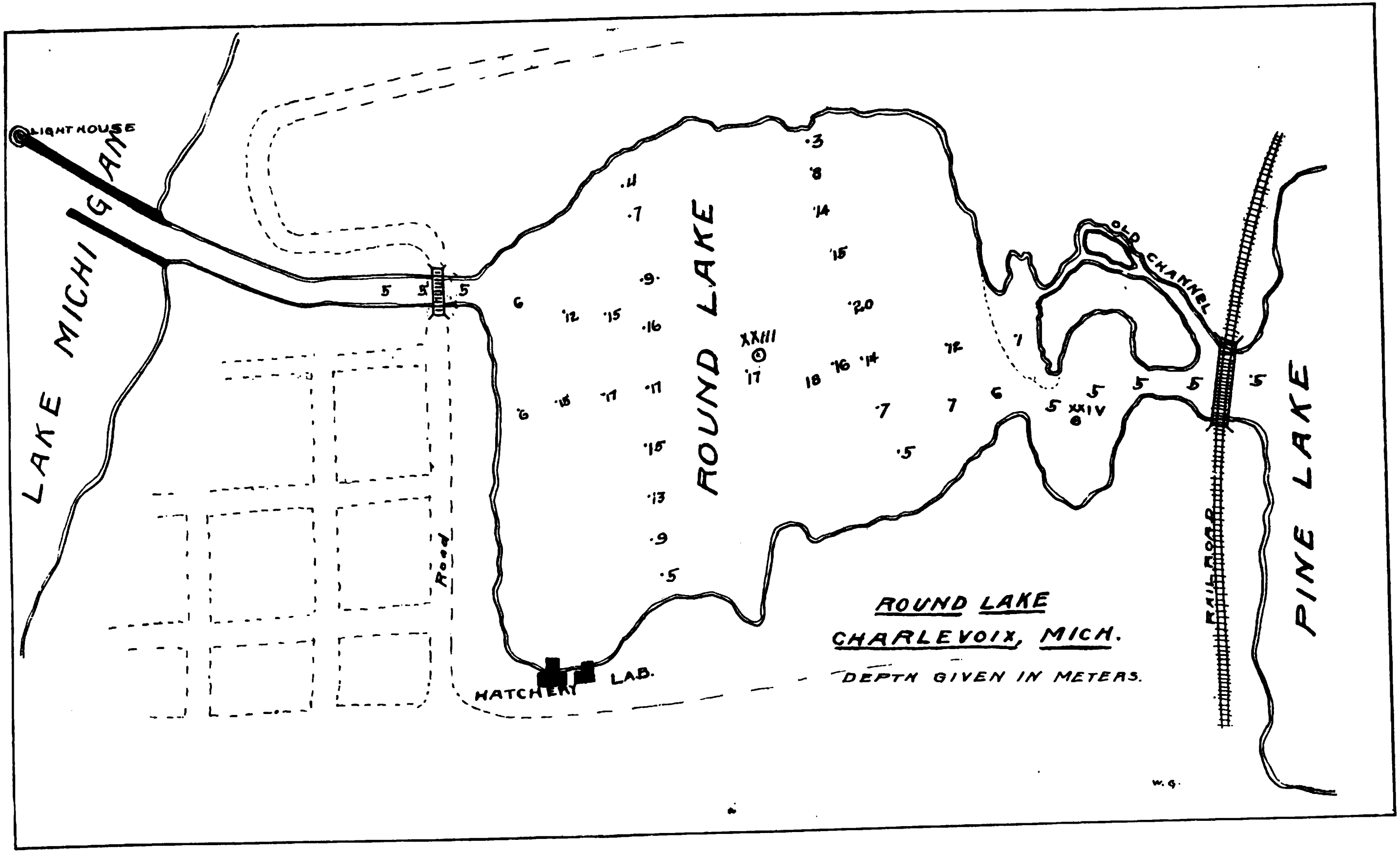

ROUND LAKE
CHARLEVOIX, MICH.
DEPTH GIVEN IN METERS.
ROUND LAKE
PINE LAKE
LAKE MICHIGAN
LIGHTHOUSE
OLD CHANNEL
RAILROAD
HATCHERY
LAB.
Road
XXIII
XXIV

PLATE IV.